(2)

REPORT

FINAL REPORT

Evaluation of Test Methods and Requirements for Respiratory Protection Systems 21

To

C. M. Grove, W. D. Kuhlmann

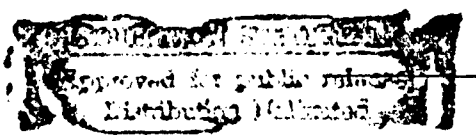
Advanced Protective Systems Integrated Laboratory,

Edgewood Research, Development and

Engineering Center

November 1992

Battelle
. . . Putting Technology To Work



REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	NOVEMBER 1992	FINAL REPORT

4. TITLE AND SUBTITLE
EVALUATION OF TEST METHODS AND REQUIREMENTS FOR RESPIRATORY PROTECTION SYSTEM 21.

5. FUNDING NUMBERS
DLA900-86-C-2045

6. AUTHOR(S)
Ramirez, T. L.
Perry, M. R.
Molnar, D. E.
Reed, K. M.
Grove, C. M. (ERDEC)
Kuhlmann, W. D. (ERDEC)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
BATTELLE DAYTON OPERATIONS
WRIGHT POINT 2
5100 SPRINGFIELD PIKE
DAYTON, OH 45431-1231

8. PERFORMING ORGANIZATION REPORT NUMBER
CBIAC-SS-335

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US ARMY EDGEWOOD RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
EDGEWOOD AREA
ABERDEEN PROVING GROUND, MD 21010-5423

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
STUDY PERFORMED UNDER CHEMICAL/BIOLOGICAL INFORMATION ANALYSIS CENTER (CBIAC) CONTRACT WITH THE DEFENSE LOGISTICS AGENCY, TASK 335.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION UNLIMITED, APPROVED FOR PUBLIC RELEASE.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
THE JOINT SERVICES OPERATIONAL REQUIREMENTS (JSOR) FOR VISION, COMMUNICATIONS, RESPIRATION, THERMAL, PERONAL SUPPORT, COMPATIBILITY AND PSYCHOLOGICAL FACTORS ARE PRESENTED IN THIS SUMMARY. THE BODY OF THE REPORT PROVIDES THE TEST METHODS USED WITH OTHER PERTINENT INFORMATION. THE TEST EQUIPMENT AND COST OF EQUIPMENT ARE PROVIDED WITH RECOMMENDATIONS FOR SELECTION OF THE TEST AND THE EQUIPMENT. THE RECOMMENDATION SECTION PROVIDES A SYNOPSIS OF THE FINDINGS AND SUGGESTED EQUIPMENT THE ADVANCED PROTECTIVE SYSTEMS INREGRATION LABORATORY MAY WANT TO EVALUATE FOR USE WITH ADVANCED MASK DESIGN.

14. SUBJECT TERMS			15. NUMBER OF PAGES
RESPO21 RESPIRATORY PROTECTION JSOR	VISION COMMUNICATIONS RESPIRATION THERMAL	PERSONAL SUPPORT COMPATIBILITY PSYCHOLOGICAL FACTORS	75 16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Final Report

Evaluation of Test Methods and Requirements for Respiratory Protection Systems 21

to

Advanced Protective Systems Integration Laboratory,
Edgewood Research, Development and Engineering Center

November 1992

by

T. L. Ramirez, M. R. Perry, D. E. Molnar, and K. M. Reed

C. M. Grove and W. D. Kuhlmann

Preface

This report for the Advanced Protective Systems Integration Laboratory of the Edgewood Research, Development and Engineering Center of the Test Methods, Requirements and Recommendations for future respirator design study was prepared under the Chemical Biological Information Analysis Center (CBIAC) contract with the Defense Logistics Agency (900-86-C-2045), Task 335.

Contents

Contents (Continued)

Contents (Continued)

Figures

Tables

Executive Summary

The Joint Services Operational Requirements (JSOR) for vision, communications, respiration, thermal, personal support, compatibility and psychological factors are presented in this summary. The body of the report provides the test methods used with other pertinent information. The test equipment and cost of equipment are provided with recommendations for selection of the test and the equipment. The "Recommendation" section provides a synopsis of the findings and suggested equipment the Advanced Protective Systems Integration Laboratory may want to evaluate for use with advanced mask design.

Vision

Luminous Transmittance Requirement

The luminance transmittance shall be equal to or greater than 85 %.

Recommendation

The listed test methods are capable of providing non-subjective, quantitative evaluations of protective lens. American National Standard Institute (ANSI Z87.1-1989), MIL-V-43511 and the Canadian Standard Association (CSA-Z94.3) all advocate the use of a spectrophotometer. This device is capable of measuring absolute transmission in ultraviolet, visible and near infrared wavelength regions. Future battlefield threats may include lasers with wavelengths outside of the visible region. The wider range in wavelength monitoring capability of the spectrophotometer may prove useful when future threats become realized.

The most absolute transmittance measuring instrument is the spectrophotometer. Certain types if spectrophotometers can measure transmittance for wavelength bands from ultraviolet (190 nm) to near infrared (1100 nm). Spectrophotometer data may require more extensive processing. Processed data can provide both luminance transmittance and chromaticity coordinates. The added ability to measure transmittance in the ultraviolet and infrared regions may prove useful when future battlefield threats, such as lasers, become realized.

Haze Requirement

Haze shall be less than or equal to 5 %.

Recommendation

The Gardner Hazemeter was cited in three of the standards. The Hazemeter should be capable of providing quantitative and repeatable results.

Both the Gardner Hazegard and the Hunter Colorimeter are an adequate instrument for measuring percent haze of the mask lens. The Hunter Colorimeter can also provide chromaticity coordinates. The Hazegard is preferred because of its low cost. The need for chromaticity coordinates is not actually stated and, if desired can be provided by the spectrophotometer.

Vertical Prismatic Deviation Requirement

Vertical/horizontal prismatic deviation shall not exceed 0.18 diopters. The algebraic sum and difference of the horizontal deviation between the two center points must not exceed 0.50 and 0.18 diopters respectively.

Recommendation

Both the lensometer and focimeter type instruments are capable of providing quantitative and repeatable results. New automated lens analyzers, such as the Humphery Lens Analyzer, can not only measure prism deviation but also refractive power and cylinder. The automated Lens Analyzer may provide repeatable data.

There are two main types of instruments commonly used to measure the prism and power of lens; telescopes and focimeters. Telescopes are considered more cumbersome than focimeters due to the large amount of space they require. The focimeter (i.e., the Vertometer of Reichart Optical) is subjective which may reduce the reliability of the data. One option described by Dr. John Masso (telecon-AO Tech) is a prism testing setup developed by American Optical which measures the prism of the lens in the 'as worn' position. The protective device is placed on an Alderson 50th percentile head form and the vertical and horizontal prism deviations are measured. Perhaps the easiest method of measuring prism, refractive power and cylinder is the Humphery Lens Analyzer system. This system is compact and automated and should provide non-subjective repeatable measurements.

Refractive Power Requirement

The refractive power of the lens shall be less than or equal to 0.125 diopters.

Recommendation

Both the lensometer and focimeter should be capable of providing quantitative and repeatable results. As stated in the prism recommendations, the automated Humphery Lens Analyzer is capable of measuring prism, refractive power and cylinder.

Distortion/Definition/Astigmatism Requirement

Distortion shall be subjectively compared to the distortion standards shown in Figure 1 of Mil-V-43511B.

Recommendation

The were no quantitative (non-subjective) methods of measuring distortion identified. The Ann Arbor optical tester should provide adequate distortion assessments of protective masks.

A non-subjective method of measuring distortion was not found. Perhaps the most accurate and reproducible measuring technique would use the Ann Arbor Optical Tester. This system, with the use of a mirror, projects vertical lines through the lens twice. The resulting image can be compared with image standards to 'quantify' the measurements. Dr. Loshin of the College of Optometry at the University of Houston advocated analyzing the lens using modulation transfer functions. Although this process will not completely address the distortion issue, it does provide another method of quantifying the characteristics of a lens.

Peripheral Field-of-View Requirement

No requirements presented.

Recommendations

There are two main drawbacks to using the Haag-Streit Perimeter. The test method is subjective and it is difficult to maintain a constant focal distance from the eye to the apparatus which could lead to variability in the results. The use of the Alderson 50th percentile male head form in a goniometer should be capable of providing quantitative and repeatable results. These results should be useful in FOV comparisons between different mask types.

The most important issue to confront is the lack of requirements for peripheral FOV in the JSOR. In fact, out of the four standards reviewed, only the CSA contained FOV requirements. The CSA FOV requirements for Cup Goggles and Monoframe Goggles are listed below:

Cup Goggles: Eye-cups shall be right and left pairs and each eye-cup shall permit an effective angle of monocular vision not less than 90^{o} from a reference point 20 millimeters (mm) behind the center of the inner (rear) surface of the goggle lens.

Monoframe Goggles: The one-piece frame goggle shall permit an angle of binocular vision of not less than 60^{o} horizontally and 80^{o} vertically from two reference points 20 mm behind the inner (rear) surface of the lens and 65 mm apart, symmetrically situated in positions reasonable simulating the positions of a wearer's eyes.

The origin of the CSA requirement is uncertain. Further testing may be necessary to substantiate the FOV requirements.

The only non-subjective method of measuring field-of-view (FOV) is the goniometer device described in the CSA Z94.3. The mask being tested in the as worn position on an Alderson 50th percentile male headform is situated in the goniometer. The eyes of the headform are equipped with light sensors which detect the collimated light as the headform is rotated. This setup uses existing off-the-shelf equipment and should provide accurate, reproducible and non-subjective measurements.

There is a need for more study in this area. FOV requirements must be established. If acceptable or substantiated requirements can not be found, testing will be necessary to establish them.

Reflecting Glare and Glint Requirement

No established criteria.

Recommendation

Requirement must be defined before an appropriate test method can be identified.

Shatter Resistance Requirement

There shall be no lens fractures or object penetration.

Recommendation

Both the ANSI Z87.1 and the CSA-Z94.3 test methods are well described and should provided reliable and reproducible results for high mass impact tests. MIL-STD-662 should be followed to provide high velocity impact results. Table 5 lists the vision parameters to be tested. Included in the Table are the recommended equipment to test those parameters and the estimated cost of the equipment.

There are two basic types of shatter resistance tests; high mass and high velocity. Both tests provide valuable information. It is recommended that the high mass testing methods in ANSI Z87.1 and high velocity testing methods in MIL-V-43511 both be used.

Recommended Vision Testing Equipment

Parameter	Equipment	Estimated Cost	Comments
Luminance Transmittance	Spectrophotometer	$15k	Capable of measuring absolute transmittance from 190 nm to >2000 nm. Can also provide chromaticity coordinates. May require more extensive data analysis
Haze	Gardner Hazegard (model XL 211)	$10 k	
Prismatic Deviation and Refractive Power	Humphery Lens Analyzer	$10k	Any curved optical lens will have power, it is important to measure the mask in the as worn position. The Humphery is automated and is capable of measuring prism, power and cylinder.
Distortion	Ann Arbor Optical Tester	$2k	Subjective.
Peripheral Field-of-View	Goniometer and Alderson 50th % Headform	NA	Solely to determine if there is an obstruction.
Subjective Analysis	NA	NA	
Ballistic	Alderson 50th % Headform and projectile source.	NA	ANSI and CSA test for high mass impact. MIL tests for high velocity impact.

NA = Not available or Not Applicable

Communications

Requirement

The mask shall permit intelligible voice transmission (face to face) and shall not interfere with hearing. It shall permit the use of receiving and transmitting communication devices currently in use by the services, those now in development and those in use at the time of the new mask availability.

Recommendation

There is a strong indication that the current requirement of 75% MRT is not adequate or acceptable to the soldier in the field. Mil-Std-1472D states the 75% MRT level should not be used for operational equipment. The NATO standard of 85% MRT should be considered as the standard with 91% MRT as a design goal. Using the NATO standard will require redesign of the voicemitter and/or the use of an auditory system to assist the soldier in the field.

It is recommended that since a large monetary investment would be necessary to provide the facilities already available at the USAF Biodynamics and Bioengineering Lab that, CRDEC send any masks requiring this specialized testing to the US Air Force. The Air Force is receptive to this intergovernmental involvement, with the director of the Auditory Test Division stating he would welcome the testing for the U.S. Army. The contact for this testing is Richard McKinley at (513) 255-3660.

Respiration

Requirement

Inhalation breathing resistance shall be no greater than 55 millimeters (mm) of water at 85 liters per minute (lpm) for the field version of the mask and no greater than 70 mm of water at 85 lpm for the aviation and combat vehicle masks with attached hoses. Exhalation breathing resistance shall be no greater than 26 mm of water at 85 lpm. Under normal activity, (undefined) effective dead space shall not exceed 400 ml.

Recommendation

The research points to the development of tests which closely mimic specific tasks of the soldier's work environment. If this is the case, then the method of testing respiration should be tied to leg and arm work. This type of performance is not available on the treadmill, the treadmill can only provide a key to those tasks requiring data on marching or walking tasks. For a total understanding of the workload imposed on the human, an arm/leg ergometer is recommended. If an arm/leg ergometer is not feasible, then the leg ergometer is recommended. The U. S. Military is moving towards the use of the cycle ergometer as the standard method of physical fitness testing, replacing the 1.5-mile aerobics run. Using the ergometer would provide the researcher with repeatable baseline data for each test subject.

With the ergometer (or treadmill), the Medgraphics Metabolic Cart is recommended to collect data on aerobic, metabolic, cardiopulmonary and thermal responses. Oxygen uptake, carbon dioxide output, respiratory exchange ratio, pulmonary ventilation, ventilatory equivalent for oxygen and respiratory rate can be continuously monitored by the Medgraphics CAD/Net 2001 Metabolic Cart. The metabolic cart is an automated system that provides continuously updated data on the monitor and provides a printout of the information following the test procedures.

Breathing resistance and weight distribution can be measured in the laboratory and then correlated either to human testing results or past experience with masks. The JSOR requirement for inhalation resistance is 55 mm (max) H_2O for a one canister system field mask. For armor and air crew masks, the maximum inhalation resistance is 70 mm H_2O. The maximum exhalation resistance for both types of mask is 26 mm H_2O. Breathing resistance is currently measured by introducing a known constant flow of air (usually 85 lpm) to the inhalation/exhalation path and measuring the pressure drop across critical components such as filters and exhalation valves. Masks should be tested by sealing the mask on an Alderson 50% headform and simulate breathing. Human breathing is simulated in a sinusoidal pattern with pressure transducers mounted to measure pressure drops during the entire breathing cycle. This type of evaluation allows for a better simulation of actual wear of the mask including flows inside the mask and interference with facial features or mask structures than with constant flow evaluations. SAE ARP 1109A provides test setup for sinusoidal breathing evaluation. Table 6 provides cost data on the manufactured breathing machines available. Three companies provide breathing machines which may be connected to the Alderson headform: Test Engineering, BioSystems, Inc. and TSI.

When wearing a protective mask, resistance must be carefully controlled. If resistance is too high, respiration will be impeded and the soldier may even adopt a stance in which a leak occurs. If resistance is too low, the forces which adhere the mask to the face during inspiration would be low, increasing the risk of leaks (Cotes, 1962). Several systematic studies were conducted by Silverman (1945) which quantified the physiological response to increased breathing resistance. One of the conclusions was that the physiological responses of individuals varied considerably for each resistance condition. This points to the individual variability with which mask designers must contend. The inhalation and exhalation resistance should be kept to the minimum yet protect against seal leakage. The design goal should be to develop a mask which has all of the protection components, yet when the soldier dons the mask there is very little change in breathing resistance. This is difficult to accomplish, but the least amount of resistance which will properly seal the mask is recommended from the physiological and psychological position of the soldiers.

The amount of breathing resistance which is described as being physiologically first detectable at 10 mm H_2O at 100 lpm, first observable at 8.7 mm H_2O and 100 lpm, tolerable at 15 mm H_2O and Love (1980) concludes that total breathing resistance should be kept at about 12 - 17 mm H_2O with inspiratory resistance of 6 -14 mm H_2O. Further testing will be required to substantiate these numbers. Other than laboratory experiments, the effects on actual soldier performance of different combinations of resistance have not been studied. Most studies examine the combined effect on soldier performance of the protective mask and clothing system, therefore it is difficult to tease out of the studies degradation due to just the breathing resistance of the mask.

Filter Capacity Recommendation: As seen by the soldier, one of the most debilitating parts of the chemical protective mask is the filter system. Typically, the more experienced soldier will not put the filters in during field trials or they remove the filters as soon as they are out of sight of the test director. The filter design imposes degradation on the soldier which requires further study. The best filter would be one which contains a sensor which recognizes the gases in the air, analyzes them and

increases or decreases the protection level to protect the soldier when in a contaminated environment. When not in a contaminated environment the filters remain essentially non-existent.

A recommendation for agent testing of the mask is the use of a sinusoidal breathing system which challenges the entire mask including the filter with live agent or simulant. In the past, filter cores have been challenged at high concentration and constant flow rate for short periods of time (MIL-STD-282, for C2, M17, etc.). This provides data which are difficult to correlate with actual operational usage in a contaminated environment. This test method does not simulate human interface or operational use at all. Exhalation contamination, bi-directional flows, human interface and realistic challenge should be simulated to provide correlational results.

Dead Space Recommendation: The JSOR states that effective dead space within a protective mask's respiratory path shall not exceed 400 ml. This low volume of dead air will limit carbon dioxide buildup and increase wearability of the mask. Methods used to measure dead space are described in CWLR 2264 (U. S. Army Research Institute of Environmental Medicine, Natick, MA). Johnson (1990) concluded that dead space has minimal performance effect, perhaps as little as 5 % at high moderate to high work rates. At very high work rates, dead space by itself would be expected to have a smaller effect due to lower end-tidal CO_2 percentages, but dead space combined with mask resistance interactions at very high work rates may cause severe degradation. This degradation, in the form of hyperventilation has been seen in field exercises, but has not been documented as a direct effect of dead space.

The portion of the population with CO_2 sensitivity is between 2 and 5 %, this group has not been studied in depth, using changes in a combination of heavy work, dead space and breathing resistance to determine if the change in dead space would affect a large enough sample to be beneficial. Any change in dead space would also need to be studied concerning the psychological effects of moving the respirator closer to the face and what effect the thermal response to this change would be. The amount of sweating may not permit moving the nose cup closer to the face. There are a number of interactions which must be studied before changes in nose cup design can be made.

Thermal

Requirement

The operational temperature range as between 25°F to 120°F. There shall be no degradation in performance during wear within the temperature range. The criteria for performance of common military skills, as modified for the temperature environments, shall apply. Methods defined in the test agency's test design plan will be utilized.

Recommendation

The JSOR does not provide the level of guidance required for the problem of thermal effects on soldier performance. It is obvious from this short discussion that the effects of heat and mask design on performance should receive more study than it has in the past. Some very basic questions are going unanswered and should be evaluated in detail to provide the best mask design to the soldier.

The Advanced Protective Systems Integrated Laboratory has a thermal chamber available. Unless this chamber proves to be ineffective it is recommended that the thermal studies using human subjects be conducted in this chamber. The use of the Arm/Leg Ergometer (discussed in Respiratory Section) and the MedGraphics Metabolic Cart would provide a comparison with actual military tasks in hot/wet or hot/dry environments.

To model the effects of different clothing combinations with the mask it is recommend that the Heat Strain Model developed at ARIEM be used. This new model is based on the calculator-operated heat strain prediction model developed by the U. S. Army Research Institute for Environmental Medicine. The model can be used to determine the core temperature at various I_m/CLO, temperature, humidity and physical workload levels. The output is an equilibrium core temperature and time required to reach that temperature. This model is an excellent source for analyzing the effects of various mask and hood designs on human core temperature without the use of human subjects. Those mask designs which look most promising can then be tested using human subjects.

Personal Support

Requirement

As a minimum, the mask shall provide the wearer with a drinking capability from the canteen. The drinking device shall be capable of operating in temperatures above 32°F to a maximum of 120° F. The mask shall allow the intake of one quart of water within ten minutes. Water intake shall begin no more than 15 seconds following initiation of mouth generated sucking pressure. The time required to prepare the drinking device shall be no more than two minutes.

No requirement has been established for eating while wearing a protective mask. The Surgeon General has not accepted food intake in a chemical environment. The last work on the feeding through the mask was accomplished by Natick in 1987 (telecon-H. Miller) and has not been revitalized since then. Therefore, we did not look into the feeding procedures any further than to gain this information.

Recommendation

The testing of the drinking devices for respirators is straight forward. The only drawback is the subjective nature of the liquid intake tests. A flow rate device should be constructed to measure both time of water travel through the drinking device and the rate of liquid intake. These analyses and a subjective analysis test should be used to assess the overall compatibility of the device with the user. Since there are differences in drinking speed and esophageal response to swallowing the length, diameter and placement (location of the drinking tube and different methods of water intake) of the drinking tube requires research.

Compatibility

Requirement

The mask shall allow the satisfactory use of standard optical devices, be compatible with the sights of individual and crew-served weapons, the head harness shall not cause pressure points and meet the comfort criteria. The comfort criteria state that trained soldiers shall be capable of wearing the mask for 12 hours while performing their assigned military duties under conditions of moderate work rate (undefined) and temperate climatic conditions. The total weight of the mask, carrier and mask accessories should be as light as possible, but shall not exceed 4.0 pounds.

Recommendation

Compatibility, comfort, and fit requirements are typically verified through human performance testing. Subjects don the mask and perform normal tasks. Observation of subjects and test subject comments identify performance degradation areas caused by the mask. Also, during mask design/development, compatibility, comfort and fit concern areas can be addressed and many problems alleviated.
The JSOR states that the mask shall be designed so that the mask can be donned, whether standing, sitting, kneeling or lying prone within nine seconds by properly trained personnel. This mask characteristic can only be measured by training personnel in the proper procedures for donning the mask and timing their performance.

The following table provides the listing of various types of test equipment, the evaluated characteristic and the cost of that equipment.

Mask Protective Seal Evaluation Equipment

Company	Item	Description	Mask Characteristic Evaluated	Estimated Cost (dollars)
Shoes and Gloves (3M) (614) 885-8029	KIT #FT10	Larger than head hood, sensitivity/smell solution, fit test solution	Protection/Seal	132
Shoes and Gloves (3M) (614) 885-8029	KIT #FT20	Larger than head hood, sensitivity/smell solution, fit test solution, training videotape and case for kit.	Protection/Seal	280
Test Engineering Tom Reed (707) 445-3680	Custom	Custom breathing machines can be built based upon modification of NIOSH approved breathing machine plans.	Breathing Resistance	6,000
BioSystems, Inc. (203) 344-1079	POSI-CHECK	Breathing machine capable of measuring seal protection, breathing resistance. Seal protection is determined with a vacuum leakage test. Exhalation valve opening pressure can be measured. Face piece pressure can displayed as a function of time or simulated tank pressure.	Protection/Seal, Breathing Resistance	10,000
TSI (distributed by Instrumentation System, Inc.) Steve Snell (513) 294-2838 or (216) 845-8800 (412) 823-7005	#8020 Porta Count Plus	Respirator fit tester. Operable as stand alone test set-up or with FITPLUS IBM compatible software. Digital display, dBASE data format, printing capability.	Fit factor	7,000
TSI	#8110 Certi Test Automated Filter Tester	Ability to test HEPA grade 99.97% efficiency. Designed to meet current particulate filter respirator certification standards.	Filter Performance	29,000
TSI	#8111 accessory for #8110	Provides fit testing with challenge aerosol, easy selection of sampling times, purge times, aerosol types.	Filter Performance	2,400
TSI	#8140	Ability to test for high efficiency particulate filter cartridges (99.999999% efficient). Uses two clean room condensation nucleus counters, adjustable flow rates.	Filter Performance	54,400
TSI	#8160	Like #8140 except additionally provides determination of complete efficiency versus particle size curve (generates various sized particles)	Filter Performance	114,200
TSI	#8091 Certi Test Automated Respirator Tester	Completely programmable respiration machine and automated breathing simulator. Breathing rates/patterns are adjustable.	Breathing Resistance	12,500
TSI	#8120	Designed to allow true simulation testing with various breathing rates and challenge aerosols. Can test filter cartridges and media like #8110. #8091 is integrated to this unit.	Breathing Resistance	81,500

Psychological

Requirement

No JSOR has been established regarding the psychological aspects of protective equipment.

Recommendation

A method to study psychological effects of the mask has been developed by the U. S. Air Force. It was designed primarily for aviation studies, but was developed under a Joint Working Group for Performance Degradation in Chemical Environments with the U.S. Army as the program manager. Since the same methods for psychological studies are still in effect for mask design study this automated method lends itself to the mask study environment at the Advanced Protective Systems Integrated Laboratory. The Performance Assessment Test System (PATS) has the capability to collect, reduce and analyze psychological and physiological data. This procedure would allow for a controlled study of the respirator-human interface, which to date does not exist

Evaluation of Test Methods and Requirements for Respiratory Protection System 21

1.0 Introduction

The purpose of this report is to inform the Advanced Protective Systems Integration Laboratory of the methods available to test and evaluate respiratory protective devices. These devices (chemical defense protective masks) provide the maximum protection from persistent and non-persistent liquid, vapor and aerosol chemical/biological threats. It is critical to provide the soldier with a protective mask which has as few performance degrading components as possible, yet still provides a high level of protection. There is a trade-off for this high level of protection for the soldier because the protection degrades performance of military tasks. In some cases very little degradation in task performance is seen, whereas for other tasks, there is an elevated degree of degradation. This degradation is one of the primary concerns of mask designers, but in order to measure this degradation, repeatable test and evaluation criteria which more closely match tasks the soldier performs in the field must be established.

The analysis performed for this study was accomplished by visiting various locations and contacting companies which design and manufacture chemical defense (CD) masks. A partial list of organizations contacted is provided in Appendix A. The organizations responding to our request provided information concerning their testing equipment and methods.

The main areas of concern were visual testing, physiological, which includes respiration and thermal methods/equipment, and psychological testing. To a lesser degree, personal support, communications and compatibility issues were evaluated. A major need for the laboratory is the use of models and simulation tools which can be used to consider new and existing mask designs. This was the focus of the report.

2.0 Objective of Study

As presented in the Statement of Work, the following objectives were required:

Review and modify existing test methods, based on the Joint Service Operational Requirement Approved Evaluation Criteria and Values and Approved Evaluation Condition Procedures (Revised JSOR, 21 June, 1985), using the following guidelines:

1. Provide a quantitative assessment of the level of degradation in each subcategory and be compatible with existing database efforts.

2. Provide repeatable comparisons to be made using various mask systems or prototypes.

3. Isolate each degradation subcategory from the effects of other subcategories.

4. Eliminate the human variability of existing physiological testing.

5. Provide for test comparisons at different work rates and ambient environments.

6. Produce the test methods which will identify the critical parameters with each degradation subcategory and weigh these parameters to establish an overall quantitative assessment.

7. Identify and describe, in detail, all special equipment needed to conduct the tests of the given subcategories. Propose approaches for development of special equipment and the estimated costs of the equipment. Estimate suitable requirements for each of the degradation tests identified. These estimates will be based on the results of previous studies and the parameter weighing established in the first objective of this study.

3.0 Design of Study

The Joint Services Operational Requirements (JSOR) for vision, communications, respiration, thermal, personal support, compatibility and psychological factors are presented in the "Methods/Results" section, with a short discussion of some of the data applicable to the area evaluated. The test method used, if available, is presented with any other information which may be of value. The test equipment and costs of equipment are provided with recommendations for selection of the test and the equipment. The "Conclusions" section provides a synopsis of the findings and suggested equipment the Advanced Protective Systems Integration Laboratory may want to evaluate for use with advanced mask design.

4.0 Method/Results

4.1 Vision

This section lists the visual requirements and testing methods provided in the JSOR. Additional testing methods from the American National Standard Institute (ANSI Z87.1-1989), MIL-V-43511 and Canadian Standards Association (CSA-Z94.3-M88) are also provided. The visual requirements found in the JSOR are: luminance transmittance, haze, prismatic deviation, refractive power, distortion, field-of-view, subjective analysis and shatter resistance. A comparison of the JSOR testing methods with the other three standards was accomplished, with the objective to identify equipment and methods which would best evaluate the mask vision requirements listed in the JSOR. An emphasis was placed on non-subjective, quantitative evaluation methods.

4.1.1 Luminous Transmittance

4.1.1.1 Requirement

The luminance transmittance shall be equal to or greater than 85 %.

4.1.1.2 Test Methods

JSOR

The measurement of light transmission shall be for the mask only. The measurement of light transmission for the combination of mask and outserts shall be for information only.

Apparatus: Photo Research Photometer, Model 1980 and a gamma scientific standard lamp, Model RS-10 or equivalent

ANSI Z87.1-1989

The ultraviolet, luminous and infrared transmittance of all items may be determined by any suitable method, but the reference method shall be the use of a spectrophotometer and calculation using appropriate weighing factors given in Tables 1 through 4 of Appendix A of ANSI Z87.1-1989.

Since transmittance values can be affected by the choice of wavelength steps used for numerical integration, it is necessary to choose values finely-spaced enough so as to yield accurate results. While it is not envisioned that intervals smaller than those used in the Tables of Appendix A of ANSI Z87.1-1989 (represented in Tables 1 through 4 in this report) would be necessary, data are given in the International Commission on Illumination (CIE) publication for finer intervals. In most cases, wider intervals can be used; for instance, 100 nanometer (nm) intervals are often used in the infrared with more than adequate accuracy for many samples.

Ultraviolet Transmittance. The spectral weighing factors necessary for calculation of effective far-ultraviolet average transmittance are given in Table 1.

Luminous Transmittance. Luminous transmittance shall be determined by weighing spectrophotometer data with luminous sensitivity values for the CIE 1931 observer and CIE Illuminant A emittance values. These weighing factors are given in Table 2.

Infrared Transmittance. The infrared transmittance shall be determined by weighing spectrophotometer data with the relative spectral emittance of CIE Illuminant A. Values of the weighing factors are given in Table 3. (These values are close, but not identical, to those for a tungsten lamp with a glass envelope.)

Blue-Light Transmittance. Blue-light transmittance shall be determined by weighing spectrophotometer data with the factors for the Blue Light Hazard Function given in Table 4.

MIL-V-43511

Luminous Transmittance Test. The luminous transmittance of the visors shall be determined in accordance with ASTM D 1003.

Ultraviolet Transmittance Test. The erythemal ultraviolet transmittance shall be measured by a spectrophotometer.

TABLE 1

Spectral Weighting Factors S(λ) for Effective Far-Ultraviolet Average Transmittance

Wavelength (nm)	Relative Spectral Effectiveness S λ
200	0.03
210	0.075
220	0.12
230	0.19
240	0.30
250	0.43
254	0.5
260	0.65
270	1.0
280	0.88
290	0.64
300	0.30
305	0.06
310	0.015
315	0.003

NOTE: This table is a reproduction of Table 10, "Relative Spectral Effectiveness by Wavelength," from *Threshold Limit Values for Chemical Substances and Physical Agents in the Work Environment with Intended Changes for 1982*. Published by the American Conference of Governmental Industrial Hygienists.

TABLE 2

Values of Spectral Luminous Sensitivity $\bar{y}(\lambda)$ for the CIE 1931 Standard Colorimetric Observer and of Relative Spectral Emittance S(λ) for CIE Illuminant A.

λ(nm)	$\bar{y}(\lambda)$	S(λ)	λ(nm)	$\bar{y}(\lambda)$	S(λ)
380	0.0000	9.80	575	0.9154	110.80
385	0.0001	10.90	580	0.8700	114.44
390	0.0001	12.09	585	0.8163	118.08
395	0.0002	13.35	590	0.7570	121.73
			595	0.6949	125.39
400	0.0004	14.71			
405	0.0006	16.15	600	0.6310	129.04
410	0.0012	17.68	605	0.5668	132.70
415	0.0022	19.29	610	0.5030	136.35
420	0.0040	20.99	615	0.4412	139.99
			620	0.3810	143.62
425	0.0073	22.79			
430	0.0116	24.67	625	0.3210	147.24
435	0.0168	26.64	630	0.2650	150.84
440	0.0230	28.70	635	0.2170	154.42
445	0.0298	30.85	640	0.1750	157.98
			645	0.1382	161.52
450	0.0380	33.09			
455	0.0480	35.41	650	0.1070	165.03
460	0.0600	37.81	655	0.0816	168.51
465	0.0739	40.30	660	0.0610	171.96
470	0.0910	42.87	665	0.0446	175.38
			670	0.0320	178.77
475	0.1126	45.52			
480	0.1390	48.24	675	0.0232	182.12
485	0.1693	51.04	680	0.0170	185.43
490	0.2080	53.91	685	0.0119	188.70
495	0.2586	56.85	690	0.0082	191.93
			695	0.0057	195.12
500	0.3230	59.86			
505	0.4073	62.93	700	0.0041	198.26
510	0.5030	66.06	705	0.0029	201.36
515	0.6082	69.25	710	0.0021	204.41
520	0.7100	72.50	715	0.0015	207.41
			720	0.0010	210.36
525	0.7932	75.79			
530	0.8620	79.13	725	0.0007	213.27
535	0.9149	82.52	730	0.0005	216.12
540	0.9540	85.95	735	0.0004	218.92
545	0.9803	89.41	740	0.0002	221.67
			745	0.0002	224.36
550	0.9950	92.91			
555	1.0000	96.44	750	0.0001	227.00
560	0.9950	100.00	755	0.0001	229.59
565	0.9786	103.58	760	0.0001	232.12
570	0.9520	107.18			

All data from Publication CIE No. 15 (E-1.3.1.) 1971 "COLORIMETRY"

TABLE .3

Relative Spectral Emittance of CIE Illuminant A for Wavelengths from 700 nm to 2600 nm

λ	S(λ)	λ	S(λ)	λ	S(λ)	λ	S(λ)	λ	S(λ)	λ	S(λ)
700	198.28	1050	289.78	1400	232.72	1750	161.42	2100	108.61	2450	73.94
710	204.41	1060	289.28	1410	230.56	1760	159.63	2110	107.60	2460	73.15
720	210.36	1070	288.66	1420	228.40	1770	157.86	2120	106.40	2470	72.37
730	216.12	1080	287.94	1430	226.23	1780	156.10	2130	105.21	2480	71.60
740	221.67	1090	287.12	1440	224.06	1790	154.37	2140	104.04	2490	70.83
750	227.00	1100	286.20	1450	221.90	1800	152.65	2150	102.88	2500	70.08
760	232.12	1110	285.18	1460	219.74	1810	150.94	2160	101.73	2510	69.33
770	237.01	1120	284.08	1470	217.58	1820	149.25	2170	100.60	2520	68.60
780	241.68	1130	282.90	1480	215.42	1830	147.59	2180	99.48	2530	67.87
790	246.12	1140	281.64	1490	213.27	1840	145.93	2190	98.38	2540	67.15
800	250.33	1150	280.30	1500	211.13	1850	144.30	2200	97.29	2550	66.44
810	254.31	1160	278.89	1510	209.00	1860	142.68	2210	96.21	2560	65.74
820	258.07	1170	277.42	1520	206.87	1870	141.08	2220	95.14	2570	65.05
830	261.60	1180	275.89	1530	204.75	1880	139.50	2230	94.09	2580	64.37
840	264.91	1190	274.29	1540	202.64	1890	137.93	2240	93.05	2590	63.69
850	267.99	1200	272.64	1550	200.54	1900	136.38	2250	92.03	2600	63.02
860	270.86	1210	270.94	1560	198.45	1910	134.85	2260	91.01		
870	273.51	1220	269.20	1570	196.38	1920	133.33	2270	90.01		
880	275.95	1230	267.40	1580	194.31	1930	131.83	2280	89.02		
890	278.18	1240	265.57	1590	192.25	1940	130.35	2290	88.05		
900	280.21	1250	263.70	1600	190.22	1950	128.89	2300	87.08		
910	282.04	1260	261.79	1610	188.19	1960	127.44	2310	86.13		
920	283.68	1270	259.85	1620	186.18	1970	126.00	2320	85.19		
930	285.12	1280	257.88	1630	184.18	1980	124.59	2330	84.26		
940	286.39	1290	255.88	1640	182.20	1990	123.19	2340	83.34		
950	287.47	1300	253.86	1650	180.23	2000	121.80	2350	82.43		
960	288.39	1310	251.81	1660	178.28	2010	120.43	2360	81.53		
970	289.14	1320	249.74	1670	176.34	2020	119.08	2370	80.65		
980	289.72	1330	247.66	1680	174.42	2030	117.74	2380	79.77		
990	290.15	1340	245.56	1690	172.51	2040	116.42	2390	78.91		
1000	290.43	1350	243.45	1700	170.62	2050	115.12	2400	78.06		
1010	290.57	1360	241.32	1710	168.75	2060	113.83	2410	77.21		
1020	290.57	1370	239.18	1720	166.89	2070	112.55	2420	76.38		
1030	290.43	1380	237.04	1730	165.05	2080	111.29	2430	75.56		
1040	290.17	1390	234.88	1740	163.23	2090	110.04	2440	74.75		

Calculated by method given in Publication CIE No. 15 (E-1.3.1) 1971 "COLORIMETRY," p. 23, par. (b).

Values start at 700 nm to show overlap with values in Table A2 of this appendix.

TABLE .4

Spectral Weighting Factors for Blue-Light Hazard

Wavelength (nm)	Blue-Light Hazard Factors B(λ)
400	.10
405	.20
410	.40
415	.80
420	.90
425	.95
430	.98
435	1.00
440	1.00
445	.97
450	.94
455	.90
460	.80
465	.70
470	.62
475	.55
480	.45
485	.40
490	.22
495	.16
•	
500–600	10 exp [(450−λ)/50]
600–1400	.001

NOTE: This table is a reproduction of part of Table 12, "Spectral Weighting Functions for Assessing Retinal Hazards from Broad Band Optical Sources", from *Threshold Limit Values for Chemical Substances and Physical Agents in the Environment with Intended Changes for 1982*, issued by the American Conference of Governmental Industrial Hygienists.

CSA-Z94.3-M88

Measurements of luminous transmittance of lens shall be of regular transmittance with normal incidence on a 5 millimeter (mm) diameter circular portion on the component. Measurements of ultraviolet or infrared transmittance shall be of total transmittance with normal incidence on a 5 mm diameter portion of the component (i.e., with collection of both regular and diffuse transmitted radiation for measurement). A spectrophotometer or a spectroradiometer shall be used. Luminous transmittance shall be determined with standard illuminant A of the CIE. When testing for luminous transmittance in the visible range, the following reference standard shall be used: ASTM D 1003, Haze and Luminous Transmittance of Transparent Plastics. For ultraviolet and infrared, a spectrophotometer shall be used. (Note: A spectrophotometer or a spectroradiometer may be used for all luminous transmittance measurements.)

4.1.1.3 Recommendation

The listed test methods are capable of providing non-subjective, quantitative evaluations of protective lens. ANSI Z87.1, MIL-V-43511 and CSA-Z94.3 all advocate the use of a spectrophotometer. This device is capable of measuring absolute transmission in ultraviolet, visible and near infrared wavelength regions. Future battlefield threats may include lasers with wavelengths outside of the visible region. The wider range in wavelength monitoring capability of the spectrophotometer may prove useful when future threats become realized.

4.1.2 Haze

4.1.2.1 Requirement

Haze shall be less than or equal to 5 %.

4.1.2.2 Test Methods

JSOR Apparatus

Gardner Hazemeter, model UX10 and Gardner digital photometric unit, model PG-5500 or equivalent

ANSI Z87.1-1989

Lenses shall be measured for percent haze in accordance with the Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics - ASTM D 1003-61. The measurement shall be for CIE Illuminant A. Procedures cited in ASTM D 1003-61 advocate the use of the Gardner Laboratory Hazemeter.

MIL-V-43511

The haze of the visors shall be determined In Accordance With (IAW) ASTM D 1003. Procedures cited in ASTM D 1003-61 advocate the use of the Gardner Laboratory Hazemeter.

CSA-Z94.3-M88

The test shall consist of viewing, through the component, a small perfectly black hole in a apparently unlimited and uniformly bright surface. The diameter of the hole shall subtend $1° \pm 5'$ at the component. The black hole shall be viewed normally through a 5 mm diameter portion of the component. Under such conditions, the hole will appear to have some brightness due to light scattered in the component or at its surfaces. The haze of the lens, plate or cover is represented as the ratio between the apparent luminance of the hole due to this scattered light and the apparent luminance of the uniformly bright surface adjacent to the hole.

4.1.2.3 Recommendation

The Gardner Hazemeter was cited in three of the standards. The Hazemeter should be capable of providing quantitative and repeatable results.

4.1.3 Vertical Prismatic Deviation

4.1.3.1 Requirement

Vertical/horizontal prismatic deviation shall not exceed 0.18 diopters. The algebraic sum and difference of the horizontal deviation between the two center points must not exceed 0.50 and 0.18 diopters respectively.

4.1.3.2 Test Methods

JSOR Apparatus

American Optical Company focimeter which is calibrated for prismatic deviation units of 0.1 prism diopter and has a maximum range of 0.50 prism diopter. Measurements of vertical and horizontal deviation will be made at the center points.

ANSI Z87.1-1989

Prismatic Power. The lenses may be tested for prismatic power with a telescope of 8 ± 0.5 power which has an effective aperture of 19 mm (.75 in) and is equipped with crosshairs in the focal plane of the ocular. The telescope is to be focused on an illuminated "sunburst" target (Figure 20 in ANSI Z87.1, Figure 1 in this report), comprised of a central dot and a concentric circle 13.3 mm (.52 in) in diameter, at a distance of 10.67 m (420 in) from the telescope objective. The telescope is to be so aligned that the image of the central dot falls on the intersection of the crosshairs in the focal plane of the ocular. The lens to be tested is held in front of the objective lens of the telescope and, if the intersection point of the crosshairs falls outside the image of the circle, the prismatic power of the lens exceeds 1/16 prism diopter.

Prism Imbalance. The protective device shall be placed on an Alderson 50th percentile male headform in an "as worn" position in the optical system shown in Figure 2 (Figure 21 from ANSI Z87.1-1989). Referring to Figure 2, the lens (L) is located at a distance of 2 m (78.7 in) in front of the image plane. Since the lens L has a focal length of 1 m (39.4 in), the distance from the plate P to the lens will be approximately 2 m (78.7 in). The pinhole aperture in plate P is adjusted so that one image is formed in the image plane when no protector is on the headform. The position of that image

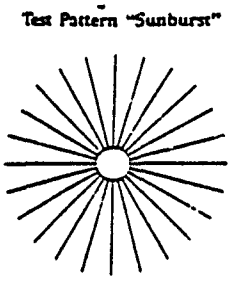
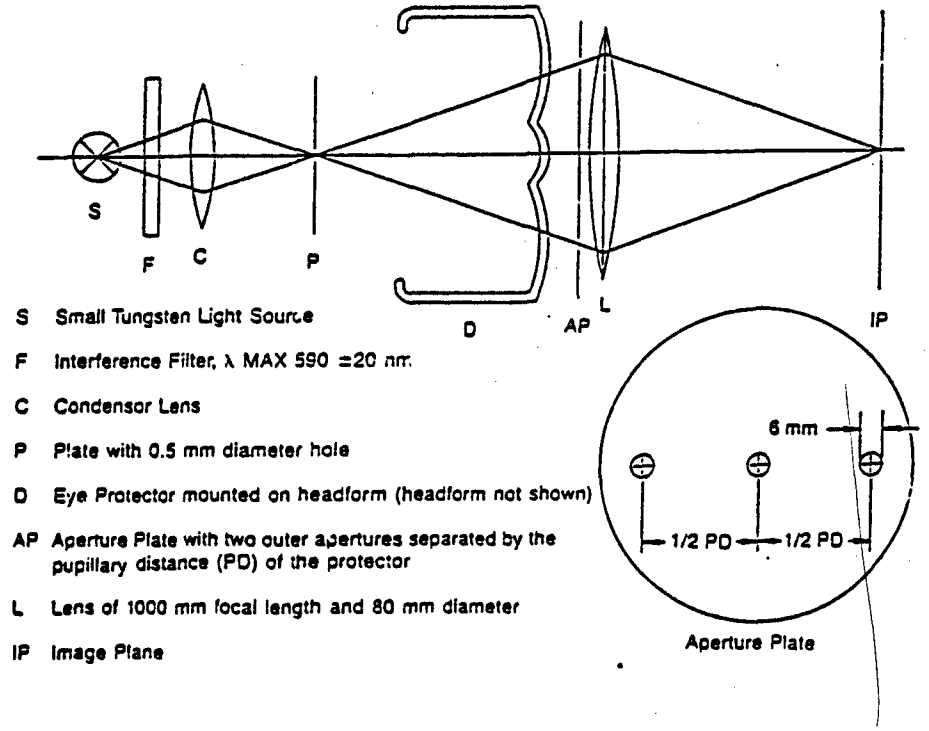


Figure 1. Sunburst Test Pattern



S Small Tungsten Light Source

F Interference Filter, λ MAX 590 ±20 nm

C Condensor Lens

P Plate with 0.5 mm diameter hole

D Eye Protector mounted on headform (headform not shown)

AP Aperture Plate with two outer apertures separated by the pupillary distance (PD) of the protector

L Lens of 1000 mm focal length and 80 mm diameter

IP Image Plane

Figure 2. Prism Imbalance Test Apparatus

should be marked or noted and will be called P_0. After the protector has been placed in the system, two images will usually be seen in the image plane.

Analysis of Results. In the case of a mask having zero prism imbalance, one image may be seen in the image plane, while in the usual case two images will be seen. By blocking beams from the two eye positions, it can be determined which images come from the left and right eye. The position of these images will be called P_L and P_R.

The prismatic power in prism diopters of the protector is one-half the distance in centimeters between P_0 and either P_L or P_R, whichever is greater.

The horizontal distance between the two images in centimeters divided by two is the horizontal prism imbalance in prism diopters, while the vertical separation of the two images in centimeters divided by two is the vertical prism imbalance.

For an observer looking at a translucent image plane from behind (and hence looking toward the headform from behind the image plane), if the right one of the two images comes from the right aperture in the aperture plate, then the horizontal prism imbalance is "base out," while if the left image comes from the right aperture, then the horizontal prism imbalance is "base in".

Distances between images are measured from their centers. After the pinhole aperture has been sharply imaged in the image plane without the protector in the system, no component spacing should be changed.

MIL-V-43511

Prismatic Deviation Test. A telescope, lensometer projection lantern or any other suitable instrument shall be used to test the prismatic deviation. The instrument shall include a target which can be brought into sharp focus, as observed through an eyepiece or projected upon a screen, and an aperture not over one centimeter in diameter fixed at a definite position along the axis of the optical system. The design of the instrument shall be such that the refractive power in the principal meridian of the visor placed across the test aperture can be determined to within 0.03 diopter. The applicable paragraph of National Bureau of Standards Special Publication 374, may be used as a guide or a method of checking refractive power. Vertical and horizontal prismatic deviations shall apply to readings taken on the visor "as worn" with the distance of 1.70 inches from the concave surface of the visor when instruments other than the lensometer are used. All measurements shall be made in areas delineated in the end item specification, drawing, or contract, as applicable.

Vertical Prismatic Deviation. Base up prism shall be designated positive (+) and base down prism shall be designated negative (-). The vertical prismatic deviation is calculated by determining the algebraic difference between point "C" for the right eye and point "C" for the left eye, as well as comparison of other points as stated in Section 3.4 of MIL-V-43511. "C" shall be identified as the center point for the left and right optics.

Horizontal Prismatic Deviation. Base out prismatic deviation (deflection of target to the left for the left side of the visor as worn, and deflection of the target to the right for the right side of the visor as worn) shall be designated positive (+) and base in prismatic deviation (deflection of the target to the right for the left side of the visor as worn, and deflection of the target to the left for the right side of the visor as worn) shall be designated negative (-). The algebraic sum of horizontal prismatic deviation

at points "C" and all other points of choice for the right and left eyes shall not exceed 0.50 diopters. The algebraic difference between the horizontal prismatic deviation at points "C" and all other points of choice for the right and left eyes shall not exceed 0.18 diopters.

CSA-Z94.3-M88

The component shall be tested for deviation of incident light passing through all 5 mm diameter portions of the component up to 3 mm from the edge. The light shall be normally incident on the front surface of the lens. An exception shall be made for any optical component for which the specific optical design indicates the suitability of a different criterion for direction of incident light (e.g., for zero-power "6-base" spectacle lenses, the light shall be incident parallel to the lens axis).

4.1.3.3 Recommendation

Both the lensometer and focimeter type instruments are capable of providing quantitative and repeatable results. New automated lens analyzers, such as the Humphery Lens Analyzer, can not only measure prism deviation but also refractive power and cylinder. The automated Lens Analyzer may provide repeatable data.

4.1.4 Refractive Power

4.1.4.1 Requirement

The refractive power of the lens shall be less than or equal to 0.125 diopters.

4.1.4.2 Test Methods

JSOR Apparatus

American Optical Company focimeter which is calibrated in units of 0.01 diopter and has a maximum range of $\pm$ 0.30 diopter. Mask will be positioned in focimeter approximately as worn and measurements are taken at the left and right center points.

ANSI Z87.1-1989

Refractive Power and Astigmatism. The lens may be tested for refractive power by any suitable instrument, such as a telescope employing an objective lens and having a clear aperture of approximately 19 mm (.75 in). The telescope should be of 8 ± 0.5 power, and be focused at a distance of 10.67 m (420 in) on an illuminated "sunburst" test pattern Figure 1 described in Section 15.4.2 of ANSI Z87.1, Figure 20. The quality of the telescope and the observer's vision should be such that Pattern 40 of the high contrast test chart of NBS Special Publication 374 is resolved when no lens is in front of the telescope.

If lines in only one meridian appear sharpest at a given focus, then the telescope is refocused to determine best focus for lines in the meridian which yield an extreme (maximum or minimum) power reading. This power reading is noted. The telescope is then refocused for lines in the meridian which yield the opposite extreme power reading. This reading is also noted. The absolute difference in the two extreme power readings is the astigmatism.

MIL-V-43511

The refractive power shall be determined with the same apparatus used for measuring prismatic deviation.

CSA-Z94.3-M88

No requirements.

4.1.4.3 Recommendation

Both the lensometer and focimeter should be capable of providing quantitative and repeatable results. As stated in the prism recommendations, the automated Humphery Lens Analyzer is capable of measuring prism, refractive power and cylinder.

4.1.5 Distortion/Definition/Astigmatism

4.1.5.1 Requirement

Distortion shall be subjectively compared to the distortion standards shown in Figure 1 of Mil-V-43511B.

4.1.5.2 Test Methods

JSOR Apparatus

Ann Arbor Optical tester using a 60-line grating. Optical distortion of the defined critical area of the test sample shall be determined by inserting the sample with its surface normal to the line of sight into the testing apparatus.

ANSI Z87.1-1989

After the test for refractive power and astigmatism, the telescope is then refocused for the best compromise focus, that is, until all radial lines appear equally sharp. The test chart of Figure 20 is replaced by the high contrast test chart of National Bureau of Standards Special Publication 374, which should be at a distance of 10.67 m (420 in) from the telescope and approximately centered in its field of view. If the observer judges Pattern 20 to be clearly resolved in both orientations, then the lens passes the requirement for definition. If the observer judges that Pattern 20 is not clearly resolved in both orientations, the lens fails the definition requirement. The telescope may be calibrated by the methods given in Appendix E of ANSI Z87.1-1989.

MIL-V-43511

The optical distortion of the critical areas of the visors shall be determined by inserting the visor with its surface normal to the line of sight into the apparatus described in Figure 3 of MIL-V-43511. The degree of off-parallelism shall constitute the amount of distortion. The visor shall be compared with the plates in Figure 1 of MIL-V-43511. The apparatus identified in MIL-V-43511 is the Ann Arbor Optical tester

CSA-Z94.3-M88

The target for the test shall consist of a series of sizes of bright rings on a black background as illustrated in Figure 5 of CSA-Z94.3. Each ring shall have an inside diameter equal to 1/3 of its outside diameter. The effective size of each ring shall be designated by the arithmetic mean of the two diameters, as expressed in seconds of arc, subtended at the objective of the viewing telescope. The telescope shall be 5 mm or more from the target and shall have a magnification sufficient to make negligible any effects of eye accommodation (8X to 12X will usually be suitable). It shall be focused with no sample in place and shall not be refocused during testing. The clear aperture of the telescope objective shall be masked to 5 mm in diameter. The system shall be of at least sufficient quality to permit resolution of the 40-s ring. This resolution shall be maintained at all image brightness to be used in testing. The lens, plate or cover to be tested shall be placed immediately in front of the telescope objective and normal to its axis.

A ring considered resolved if it is identifiable as an unbroken bright ring with a single darker center, even though apparent relative widths of ring and center are changed or the ring and its center cease to appear circular. The ring is not resolved if the ring is broken, if the dark center is not seen or if two or more dark centers that do not overlap are seen.

4.1.5.3 Recommendation

The were no quantitative (non-subjective) methods of measuring distortion identified. The Ann Arbor optical tester should provide adequate distortion assessments of protective masks.

4.1.6 Peripheral Field-of-View

4.1.6.1 Requirement

No requirements presented.

4.1.6.2 Test Methods

JSOR Apparatus

Haag-Streit Perimeter. The target stimulus will be a high contrast 1 mm diameter white light circle which is projected and centered on a hemisphere at a distance of 33 cm from the test subjects eye. The stimulus luminance will be 54 footlamberts against a background of approximately 0.25 footlamberts. Meridional measurements will be made monocularly for the left and right eyes at 15 degree intervals.

ANSI Z87.1-1989

No test methods.

MIL-V-43511

No test methods.

CSA-Z94.3-M88

All field-of-view (FOV) tests shall be conducted on complete eye-protective devices that are mounted in the same position as usually worn on a facially featured Alderson 50th percentile male (ATD-3215) headform. Each pupil target shall be 4 mm in diameter and represented by a light sensor. A mechanical means such as a goniometer and a light source such as a laser beam shall be employed to perform the following tests. The goniometer shall be used to rotate the headform with the complete eye-protective device within 0.1° of accuracy. The angular rotation of the goniometer enables a spherical scan of the eye-protective device FOV to be made. (A goniometer is a positioner device which moves the headform in horizontal and vertical directions. The goniometer is interfaced with a computer, thereby providing a computer printout of the FOV test charting measurement.)

A laser shall be used as the light source for identifying the pupil target. A beam expander, connected to the laser, generates a 3 mm diameter light beam. (A laser is used because it provides a monochromatic, concentrated beam of light. A helium-neon laser with 0.5 milliwatts (mW) power is recommended.)

The alignment calibration shall be conducted to ensure that the laser beam remains on the pupil target during all headform rotations. This calibration ensures the pupil target remains in the same spatial orientation (i.e., the imaginary center of the goniometer). Initially, the headform is placed on the goniometer, the laser beam is energized and the headform is adjusted so the laser beam contacts the pupil target. By rotating the headform through all degrees of rotation of the test zone, the alignment is verified.

The eye protector device shall be placed on the headform. The head form is then rotated through all degrees of rotation of the test zone. This test zone is a semisphere within which the FOV exists. A sufficient number of FOV measurements shall be taken with the semisphere test zone to ensure the identification of the peripheral FOV and scotoma. The left eye and right eye FOV charts are superimposed and interpreted. When the eye protector blocks the laser beam from contacting the light sensor target, it will not indicate an output signal. This state is interpreted as the end point of the peripheral FOV of vision or a scctoma.

4.1.6.3 Recommendation

There are two main drawbacks to using the Haag-Streit Perimeter. The test method is subjective and it is difficult to maintain a constant focal distance from the eye to the apparatus which could lead to variability in the results. The use of the Alderson 50th percentile male head form in a goniometer should be capable of providing quantitative and repeatable results. These results should be useful in FOV comparisons between different mask types.

The most important issue to confront is the lack of requirements for peripheral FOV in the JSOR. In fact, out of the four standards reviewed, only the CSA contained FOV requirements. The CSA FOV requirements for Cup Goggles and Monoframe Goggles are listed below:

Cup Goggles: Eye-cups shall be right and left pairs and each eye-cup shall permit an effective angle of monocular vision not less than 90° from a reference point 20 milimeters (mm) behind the center of the inner (rear) surface of the goggle lens.

Monoframe Goggles: The one-piece frame goggle shall permit an angle of binocular vision of not less than 60^{o} horizontally and 80^{o} vertically from two reference points 20 mm behind the inner (rear) surface of the lens and 65 mm apart, symmetrically situated in positions reasonable simulating the positions of a wearer's eyes.

The origin of the CSA requirement is uncertain. Further testing may be necessary to substantiate the FOV requirements.

4.1.7 Reflecting Glare and Glint

4.1.7.1 Requirement

No established criteria.

4.1.7.2 Test Methods

JSOR

Subjective comparisons should be made with standard masks under operational conditions for reflected glare and glint.

4.1.7.3 Recommendation

Requirement must be defined before an appropriate test method can be identified.

4.1.8 Shatter Resistance

4.1.8.1 Requirement

There shall be no lens fractures or object penetration.

4.1.8.2 Test Methods

JSOR

Mask lens shall be tested for resistance to blunt impact and sharp object penetration as specified in ANSI Z87.1 - 1979. The mask with outserts shall be tested in the "as worn" configuration.

ANSI Z87.1-1989

High Velocity Impact Test

Purpose: This test is intended to ensure a level of protection from high velocity, low mass projectiles. The projectiles used for this test shall be 6.35 mm (1/4 in) diameter steel balls weighing approximately 1.06 gram (.04 ounce). These balls are damaged during impact and should be changed frequently to avoid impacts at unexpected locations ("flyers") and large variations in velocity.

Test Apparatus: The test apparatus shall consist of any device capable of propelling a steel ball reproducibly at the velocities called out in this standard. Specifically, if the desired test velocity is called V_0, then the device shall show a sample standard deviation not greater than 2 % of V_0 based on a test series of thirty shots. Velocity of the steel ball shall be determined at a distance not greater than 25 cm (9.8 in) from point of impact. Information about a typical "air-gun" configuration is given in Appendix C of ANSI Z87.1-1989

The protective device shall be mounted on an Alderson 50th percentile male headform in the manner in which the device is usually worn. The headform shall be capable of being rotated about a vertical axis through each corneal vertex in 15° increments, from a first position 15° to the nasal side of straight-ahead-viewing out to 90° temporally. (It is assumed that the headform is vertical such that the two eyes lie in a horizontal reference plane.) The headform shall be capable of being raised 10 mm (.394 in) and lowered 10 mm (.395 in) with respect to the horizontal reference plane to carry out testing at the 90° angular position.

Testing Complete Devices, Front and Side Impacts: The headform shall be adjusted so that the path of the projectile passes through the center of either of the eyes. It is then rotated to the first test position, which is 15° on the nasal side. The device is impacted at the test velocity. A new device is then placed on the headform and impacted at 0°, another is impacted at 15° temporally, and so on, until eight devices have been impacted, the last at an angle of 90°. These eight devices, then, have been impacted at various points in the horizontal reference plane containing the eyes of the headform. At the 90° angular position, one device shall be impacted 10 mm (.394 in) above the plane of the eyes of the headform. Hence the total group size tested about one eye is ten samples. A similar test is then carried out about the other eye, resulting in a total of twenty samples tested.

Testing Spectacles Without Side Protection: When testing spectacles without side protection, one proceeds as in Section 15.1.3 of ANSI Z87.1-1989 until reaching the angle where the lens or front is no longer impacted. Starting back at the 15° nasal position on the same side, additional samples should be tested 15° nasal, 0°, 15° temporal, until ten samples have been tested on that side of the headform. A similar procedure is then carried out on the other side of the headform, resulting in a total of twenty samples tested.

Analysis of Results: Failure criteria are those given in Sections 8 through 11 of ANSI 287.1-1989 for the particular type of device being tested. For sample sizes of twenty involved in Sections 15.1.3 and 15.1.4 of ANSI Z87.1-1989, if more than one failure occurs, the device fails.

High Mass Impact Test

Purpose. This test is intended to ensure a level of mechanical integrity of a protective device and a level of protection from relatively heavy, pointed objects traveling at low speed.

Test Apparatus: An Alderson 50th percentile male headform shall be used to hold the protective device. It shall be rigidly mounted in the horizontal position, face up, on a base which has a mass of 30 kg (66 lb.) or greater. The static stiffness of the headform shall be such that when a vertical downward force of 20 kg (44 lb) is applied to the forehead of the headform, the back of the headform shall not deflect more than 2 mm (.079 in). The missile shall have a 30° conical tip with a 1 mm (.039 in) radius, shall weigh 500 grams (17.6 ounces), and have a diameter of 25.4 mm (1 in), as shown in Figure 19 of ANSI Z87.1-1989. The missile will be held in position over the headform, tip down, at the designated test height. The missile shall have a heat-treated steel tip. The missile shall be dropped

through a loose-fitting guide tube having a smooth internal diameter; this prevents missile tumble and helps to protect the operator if the tube extends to within a short distance of the device being tested, and allows just sufficient room for insertion of the missile at the top. Partial shielding of the headform may be advisable to protect the operators feet.

Testing: The protective device is placed on the headform as it would be worn by the user. The alignment shall be such that when the missile is dropped, its point is in line with either of the eyes of the headform.

The missile shall be dropped from the designated testing Height H_0. Four samples shall be tested.

Analysis of Results: Failure criteria are those given in Sections 8 through 11 of ANSI Z87.1-1989 for the particular type of device being tested. If all four samples pass, then the device passes. If any fail, then the device fails.

MIL-V-43511

Impact Resistance Test. The impact test shall be conducted in accordance with MIL-STD-662 and using a caliber .22 T37 fragment simulating projectile. The visor shall be rigidly mounted with the area to be impacted normal to the line of fire. An aluminum foil witness sheet, 2 mils thick, shall be mounted 2 inches behind the area of impact. Three valid impacts shall be make on the visor; one in the center and one in each vision area. An impact shall be considered valid only if it meets any of the following criteria:

1. The impact velocity of the projectile is between 550 and 560 ft/second.

2. The impact velocity of the projectile is less than 550 ft/second and the impact fails to meet the requirements in 3.5.10

3. The impact velocity of the projectile is more than 560 ft/second and the impact meets the requirements in 3.5.10.

The visor containing the three valid impacts and the witness sheet shall be examined for conformance to the requirements of 3.5.10 of MIL-V-43511. Any penetration on the witness sheet shall be considered evidence of spall.

Abrasion Resistant Coating. The abrasion resistance coating test shall be conducted IAW MIL-C-83409.

CSA-Z94.3-M88

Impact Resistance Test. The headform on which the eye protector is mounted during the test shall be Alderson, Model ATD-3215, 50th percentile male. All impact test shall be conducted on complete eye-protective devices that are mounted on a facially featured head from of the appropriate size and mounted in the same position as usually worn. The headform shall be rigidly mounted. Propulsion equipment shall be capable of propelling a 6.5 mm (1/4 in) steel ball horizontally at speeds of 14 $\pm$0.5 m/s (46 ft/s) and 18 $\pm$ 0.5 m/s (59 ft/s). (Note: This equipment consists essentially of a barrel or a tube of sufficient length to ensure constant exit velocity of a steel ball, together with a breech or loading mechanism positioning the steel ball at a fixed position from the barrel or tube end, and a

spring or compressed gas to provide the means of propulsion. The length of tube or smooth barrel required is a function of the characteristics of the gas supply or spring used for propulsion and the fit of the ball in the tube. Therefore, each individual apparatus may have different characteristics and it is not possible to define precise requirements for the length of the barrel and the fit of the ball in the bore in the standard.)

The speed of the test ball shall be determined using timing equipment recording in units of 10 microseconds (μs) or smaller. The recommended method is to use an electronic timer with detectors that may be of the inductance, capacitance or light-sensitive type. The detectors shall be mounted near the projectile path between the muzzle end of the barrel and the lens under test. The recording of velocities shall be made not further than 250 mm (10 in) from the point of impact. (Note: The accuracy of the timing unit is dictated by the spacing between the sensing elements and the accuracy that is required for the ball-velocity measurement. Present indications are that the spacing between the sensing elements should not exceed 150 mm (6 in) and that, with this particular spacing and the highest velocity envisaged, the accuracy of the timing unit should be as stated in order to allow for variations on other points and still keep the overall velocity within the limits specified.)

Test method: This test is carried out on the basis of assessing resistance to a single impact at any point on the components described in Clause 5.1.1 of CSA-294.3-1988. Thus, there shall be only impact on a selected point and no impact on a point where likelihood of failure may have been significantly increased by a previous nearby impact (e.g., a spectacle lens that had been impacted at its center would not the be impacted at its edge).

Points of impact shall be selected to establish the impact resistance of the whole protector. Some suggested points of impact are as follows:

1. Lens center
2. Outer edge of the lens or sid attachment
3. Side shield
4. Inner edge of the lens by the nose
5. Side of the goggles, cup or frame.

The protective device shall be weighed and placed on the headform in the position as usually worn. A piece of carbon paper above a piece of white paper, each of adequate size, shall be placed between the protective device and the headform. The assembled headform and protective device shall be placed before the propulsion equipment. The steel ball shall be projected at the appropriate velocity, specified in Clause 5.1 of CSA-Z94.3-M88, against the protective device. The protective device shall be reweighed to determine amount of material detached, if any.

4.1.8.3 Recommendation

Both the ANSI Z87.1 and the CSA-Z94.3 test methods are well described and should provided reliable and reproducible results for high mass impact tests. MIL-STD-662 should be followed to provide high velocity impact results. Table 5 lists the vision parameters to be tested. Included in the table is the recommended equipment to test the parameters and the estimated cost of the equipment.

Table 5. Recommended Vision Testing Equipment

Parameter	Equipment	Estimated Cost	Comments
Luminance Transmittance	Spectrophotometer	$15k	Capable of measuring absolute transmittance from 190 nm to >2000 nm. Can also provide chromaticity coordinates. May require more extensive data analysis
Haze	Gardner Hazegard (model XL 211)	$10 k	
Prismatic Deviation and Refractive Power	Humphery Lens Analyzer	$10k	Any curved optical lens will have power, it is important to measure the mask in the as worn position. The Humphery is automated and is capable of measuring prism, power and cylinder.
Distortion	Ann Arbor Optical Tester	$2k	Subjective.
Peripheral Field-of-View	Goniometer and Alderson 50th % Headform	NA	Solely to determine if there is an obstruction.
Subjective Analysis	NA	NA	
Ballistic	Alderson 50th % Headform and projectile source.	NA	ANSI and CSA test for high mass impact. MIL tests for high velocity impact.

NA = Not available or Not Applicable

The following recommendations are from conversations with several reputable vision testing individuals: Dr. John Masso, AO Tech Corp.; Ili Szamosi, CSA; Dr. Arol Ougsburger and Dr. Gregory Good, College of Optometry, Ohio State University; Dr. Dave Loshin, College of Optometry, University of Houston.

Luminance Transmittance. The most absolute transmittance measuring instrument is the spectrophotometer. Certain types if spectrophotometers can measure transmittance for wavelength bands from ultraviolet (190 nm) to infrared (>2000nm). Spectrophotometer data may require more extensive processing. Processed data can provide both luminance transmittance and chromaticity coordinates. The added ability to measure transmittance in the ultraviolet and infrared regions may prove useful when future battlefield threats, such as lasers, become realized.

Haze. Both the Gardner Hazegard and the Hunter Colorimeter are adequate instruments for measuring percent haze of the mask lens. The Hunter Colorimeter can also provide chromaticity coordinates. The Hazegard is preferred because of its low cost. The need for chromaticity coordinates is not actually stated and, if desired, can be provided by the spectrophotometer.

Prism Deviation and Refractive Power. There are two main types of instruments commonly used to measure the prism and power of lens; telescopes and focimeters. Telescopes are considered more cumbersome than focimeters due to the large amount of space they require. The focimeter (i.e., the Vertometer of Reichart Optical) is subjective which may reduce the reliability of the data. One option described by Dr. John Masso (telecon-AO Tech) is a prism testing setup developed by American Optical which measures the prism of the lens in the 'as worn' position. The protective device is placed on an Alderson 50th percentile head form and the vertical and horizontal prism deviations are measured. Perhaps the easiest method of measuring prism, refractive power and cylinder is the Humphery Lens Analyzer system. This system is compact and automated and should provide non-subjective repeatable measurements.

Distortion. A non-subjective method of measuring distortion was not found. Perhaps the most accurate and reproducible measuring technique would use the Ann Arbor Optical Tester. This system, with the use of a mirror, projects vertical lines through the lens twice. The resulting image can be compared with image standards to 'quantify' the measurements. Dr. Loshin of the College of Optometry at the University of Houston advocated analyzing the lens using modulation transfer functions. Although this process will not completely address the distortion issue, it does provide another method of quantifying the characteristics of a lens.

Peripheral Field-of-View. The only non-subjective method of measuring field-of-view (FOV) is the goniometer setup described in the CSA Z94.3-1988. The mask being tested in the as worn position on an Alderson 50th percentile male headform which is situated in the goniometer. The eyes of the headform are equipped with light sensors which detect the collimated light as the headform is rotated. This setup uses existing off-the-shelf equipment and should provide accurate, reproducible and non-subjective measurements.

There is a need for more study in this area. FOV requirements must be established. If acceptable or substantiated requirements can not be found, testing will be necessary to establish them.

Subjective Analysis. The requirements for subjective analysis must be addressed.

Shatter Resistance. There are two basic types of shatter resistance tests; high mass and high velocity. Both tests provide valuable information. It is recommended that the high mass testing methods in ANSI Z87.1 and high velocity testing methods in MIL-V-43511 both be used.

4.2 Communications

4.2.1 Requirement

The mask shall permit intelligible voice transmission (face to face) and shall not interfere with hearing. It shall permit the use of receiving and transmitting communication devices currently in use by the services, those now in development and those in use at the time of the new mask availability.

4.2.2 Test Method

Given the importance of effective voice communication in any setting, much study has been conducted to develop intelligibility tests and evaluation facilities. Since voice communication can be affected by many factors including electrical and/or acoustical noise, radio interference, jamming, and communication signal processing, not only must these tests and facilities simulate aspects of regular voice communication and sound environments, but they should also identify where and why a given system degrades effective voice communication. If problem areas can be identified, it becomes possible to correct deficiencies and even enhance communication capability.

The most widely used intelligibility test is the Modified Rhyme Test (MRT). This test is composed of several lists of monosyllabic words which are presented to a listener via a standardized tape or speaker. The listener is responsible for identifying the words. The test uses words that are very similar, differing perhaps only in the leading consonant. Failure to identify words correctly may imply that the system being evaluated (helmet, mask, etc.) causes attenuation and/or distortion of sounds. Identification of specific sounds that are less intelligible may direct the system designers to flaws in

their design and subsequently, corrections for those flaws. Typically, the MRT is performed in controlled settings, ideally in a reverberation chamber.

The U.S. Air Force Armstrong Aerospace Medical Research Laboratory's Biodynamics and Bioengineering Division has two reverberation chambers currently operational. Each chamber can accommodate up to ten test subjects to which the MRT can be administered simultaneously. Through the use of large sound systems, the chambers can simulate sound environments such as flying aircraft interiors. Other factors can be changed including microphones, earphones, helmets, oxygen masks, jamming signal type and modulation, jammer to signal power ratios, and receiver input power. An air respiration system is also included. These chambers have proven to provide accurate simulations of actual voice communication environments.

Another test of a mask's voicemitter can be conducted using the Rasti equipment. This test uses a special sound room designed to test the audition emitted from a mask. The sound proof room has a mannequin head set at a specific height with four microphones to pick up the emitted sounds and transfer them to the computer, providing the hertz level coming through the mask. The computer then produces graphs on the sound and the distance the sound carries and the strength of the sound. The Rasti provides an excellent first look at the voice emitting capability of the mask; however, it does not allow for voice variability, different sounds of language or the problems with messages sent over electronic equipment (i.e., telephone, intercom).

When the designer is only interested in how the system will attenuate sound in general, an isolated reverberation chamber is used along with a sound generator. These chambers are built in accordance with ANSI S12.6-1984. The standard sets limits on ambient noise levels, reverberation time, sound pressure level uniformity, and sound field directionality, as well as measurement systems. Such chambers are necessary in the evaluation of sound attenuation to provide a controlled environment where data collected is consistent between evaluations.

The U.S. Air Force Armstrong Aerospace Medical Research Laboratory's Biodynamics and Bioengineering Division has an automated chamber that complies with ANSI S12.6-1984. The chamber can be operated through a computer system to automatically collect data using 'real-ear' attenuation at threshold and 'physical-ear' at threshold methods. The system can evaluate systems such as earplugs, earmuffs, communication headsets and helmets, active noise reduction units and combinations of these systems. The computer stores a database of results from these types of systems that can be accessed to make comparisons between similar systems. Upon finishing an evaluation, the computer determines mean attenuation for single numbers, for each third-octave band, OSHA and EPA overall noise reduction ratings and can determine daily exposure limiting duration to a given noise. Hard copy of the formatted data and attenuation plots are provided.

4.2.3 Recommendation

There is a strong indication that the current requirement of 75% MRT is not adequate or acceptable to the soldier in the field. Mil-Std-1472D states the 75% MRT level should not be used for operational equipment. The NATO standard of 85% MRT should be considered as the standard with 91% MRT as a design goal. Using the NATO standard will require redesign of the voicemitter and/or the use of an auditory system to assist the soldier in the field.

It is recommended that since a large monetary investment would be necessary to provide the facilities already available at the USAF Biodynamics and Bioengineering Lab, that CRDEC should send any masks requiring this specialized testing to the US Air Force. The Air Force is receptive to this intergovernmental involvement, with the director of the Auditory Test Division stating he would welcome the testing for the U.S. Army. The contact for this testing is Richard McKinley (513) 255-3660.

4.3 Respiration

4.3.1 Requirement

Inhalation breathing resistance shall be no greater than 55 millimeters (mm) of water at 85 liters per minute (lpm) for the field version of the mask and no greater than 70 mm of water at 85 lpm for the aviation and combat vehicle masks with attached hoses. Exhalation breathing resistance shall be no greater than 26 mm of water at 85 lpm. Under normal activity, (undefined) effective dead space shall not exceed 400 ml.

4.3.2 Test Method

Inhalation and Exhalation Resistance: Airflow resistance shall be determined using ambient conditions at a flow rate of 85 lpm using Q-123 Inhalation/Exhalation Resistance indicator or equivalent apparatus.

The effect of wearing a respirator on soldier performance interferes primarily with rifle firing, automated communication and tasks that demand aerobic capacity. Performance seems to be dependent on breathing resistance and duration of the task. Lotens (1980) found reductions in performance on 400 m and 3.1 km runs . The loss of performance found in British experiments of 22 % with the S-6 respirator compares well with Lotens 1980 data. Tests which do not demand maximum pulmonary performance show less performance decrement due to breathing resistance. There is a strong interaction effect shown between respirator and type of garment worn (Lotens, 1982).

The additional effect of the respirator is smallest for the most impeding garment. A possible explanation could be that the respirator and the garment act on different psychophysiological mechanisms, limitation of the one mechanism causing idle capacity in the other mechanism, which makes limitations of the latter less severe. In this view, effects that act on the same system should be additive. However, very little evidence exists to support this. Further research would be worthwhile since we tend to stack protective clothing on top of protective clothing with more being equated to better.

Little is known about the additivity of clothing and equipment loads. Haisman (1975) found the performance decrement of Chemical Defense (CD) protective clothing and body armor to be additive, yet there is evidence that interaction occurs between CD-protective clothing and the respirator. Without a consistent set of data obtained with one single method it is impossible to draw firm conclusions.

Firing at a range does not discriminate between garments, and not even between with/without respirator. Maneuver courses are very well suited for the measurement of performance decrement. Performance should be measured, however, for every obstacle separately. The debarkation net, the crawl and the jump discriminate well between various respirators, with digging foxholes discriminating between with/without respirator. Prolonged wear of the respirator may lead to many detrimental effects such as, sleep deprivation and decreased physical condition, negative attitude to the task, lowered alertness and morale may result. A major part of these problems are due to the respirator.

4.3.3 Recommendation

The research points to the development of tests which closely mimic specific tasks of the soldier's work environment. If this is the case, then the method of testing respiration should be tied to leg and arm work. This type of performance is not available on the treadmill, the treadmill can only provide a key to those tasks requiring data on marching or walking tasks. For a total understanding of the workload imposed on the human, an arm/leg ergometer is recommended. If an arm/leg ergometer is not feasible, then the leg ergometer is recommended. The U.S. Military is moving towards the use of the cycle ergometer as the standard method of physical fitness testing, replacing the 1.5-mile aerobics run. Using the ergometer would provide the researcher with repeatable baseline data for each test subject.

With the ergometer (or treadmill), the Medgraphics Metabolic Cart is recommended to collect data on aerobic, metabolic, cardiopulmonary and thermal responses. Oxygen uptake, carbon dioxide output, respiratory exchange ratio, pulmonary ventilation, ventilatory equivalent for oxygen and respiratory rate can be continuously monitored by the Medgraphics CAD/Net 2001 Metabolic Cart. The metabolic cart is an automated system that provides continuously updated data on the monitor and provides a printout of the information following the test procedures.

Breathing resistance and weight distribution can be measured in the laboratory and then correlated either to human testing results or past experience with masks. The JSOR requirement for inhalation resistance is 55 mm (max) H_2O for a one canister system field mask. For armor and air crew masks, the maximum inhalation resistance is 70 mm H_2O. The maximum exhalation resistance to both types of mask is 26 mm H_2O. Breathing resistance is currently measured by introducing a known constant flow of air (usually 85 lpm) to the inhalation/exhalation path and measuring the pressure drop across critical components such as filters and exhalation valves. Masks should be tested by sealing the mask on an Alderson 50% headform and simulate breathing. Human breathing is simulated in a sinusoidal pattern with pressure transducers mounted to measure pressure drops during the entire breathing cycle. This type of evaluation allows for a better simulation of actual wear of the mask including flows inside the mask and interference with facial features or mask structures than with constant flow evaluations. SAE ARP 1109A provides test setup for sinusoidal breathing evaluation. Table 6 provides cost data on the manufactured breathing machines available. Three companies provide breathing machines which may be connected to the Alderson headform: Test Engineering, BioSystems, Inc. and TSI.

When wearing a protective mask, resistance must be carefully controlled. If resistance is too high, respiration will be impeded and the soldier may even adopt a stance in which a leak occurs. If resistance is too low, the forces which adhere the mask to the face during inspiration would be low, increasing the risk of leaks (Cotes, 1962). Several systematic studies were conducted by Silverman (1945) which quantified the physiological response to increased breathing resistance. One of the conclusions was that the physiological responses of individuals varied considerably for each resistance condition. This points to the individual variability with which mask designers must contend.

The inhalation and exhalation resistance should be kept to the minimum which will protect against seal leakage. The design goal should be to develop a mask which has all of the protection components, yet when the soldier dons the mask there is very little change in breathing resistance. This is difficult to accomplish, but the least amount of resistance which will properly seal the mask is recommended from the physiological and psychological position of the soldiers.

The amount of breathing resistance which is described as being physiologically first detectable at 10 mm H_2O at 100 lpm, first observable at 8.7 mm H_2O and 100 lpm, tolerable at 15 mm H_2O and Love (1980) concludes that total breathing resistance should be kept at about 12 - 17 mm H_2O with inspiratory resistance of 6 -14 mm H_2O. Further testing will be required to substantiate these numbers. Other than laboratory experiments, the effects on actual soldier performance of different combinations of resistance have not been studied. Most studies examine the combined effect on soldier performance of the protective mask and clothing system, therefore it is difficult to tease out of the studies degradation due to just the breathing resistance of the mask.

Filter Capacity Recommendation: As seen by the soldier, one of the most debilitating parts of the chemical protective mask is the filter system. Typically, the more experienced soldier will not put the filters in during field trials or they remove the filters as soon as they are out of sight of the test director. The filter design imposes degradation on the soldier which requires further study. The best filter would be one which contains a sensor which recognizes the gases in the air, analyzes them and increases or decreases the protection level to protect the soldier when in a contaminated environment. When not in a contaminated environment the filters remain essentially non-existent.

A recommendation for agent testing of the mask is the use of a sinusoidal breathing system which challenges the entire mask including the filter with live agent or simulant. In the past, filter cores have been challenged at high concentration and constant flow rate for short periods of time (MIL-STD-282, for C2, M17, etc.). This provides data which are difficult to correlate with actual operational usage in a contaminated environment. This test method does not simulate human interface or operational use at all. Exhalation contamination, bi-directional flows, human interface and realistic challenge should be simulated to provide correlational results.

Dead Space Recommendation: The JSOR states that effective dead space within a protective mask's respiratory path shall not exceed 400 ml. This low volume of dead air space will limit carbon dioxide buildup and increase wearability of the mask. Methods used to measure dead space are described in CWLR 2264 (U.S. Army Research Institute of Environmental Medicine, Natick, MA). Johnson (1990) concluded that dead space has minimal performance effect, perhaps as little as 5 % at high moderate to high work rates. At very high work rates, dead space by itself would be expected to have a smaller effect due to lower end-tidal CO_2 percentages, but dead space combined with mask resistance interactions at very high work rates may cause severe degradation. This degradation, in the form of hyperventilation has been seen in field exercises, but has not been documented as a direct effect of dead space.

The portion of the population with CO_2 sensitivity is between 2 and 5 %, this group has not been studied in depth, using changes in a combination of heavy work, dead space and breathing resistance to determine if the change in dead space would affect a large enough sample to be beneficial. Any change in dead space would also need to be studied concerning the psychological effects of moving the respirator closer to the face and what effect the thermal response to this change would be. The amount of sweating may not permit moving the nose cup closer to the face. There are a number of interactions which must be studied before changes in nose cup design can be made.

4.4 Thermal

4.4.1 Requirement

The operational temperature range as between 25°F to 120°F. There shall be no degradation in performance during wear within the temperature range. The criteria for performance of common military skills, as modified for the temperature environments, shall apply.

4.4.2 Test Method

The JSOR states: Methods defined in the test agency's test design plan will be utilized.

Deppisch and Craig (1966) measured the rise in core temperature as a function of mask and hood wear. They reported that when wearing no mask the rate of rise in core temperature was 0.031°F/minute; wearing the M17 mask the rate was 0.036°F/minute and the rate of increase when wearing the M17 with the hood was 0.048°F/minute. This is an increase of .005°F and .017°F per minute, respectively. This, in itself is not enough rise in core temperature to produce heat casualties, but the influence of this rise in core temperature may be seen as other reactions such as dizziness, headache or slight heart rate increase. The study of the interaction of thermal effects and mask wear must be considered for different effects. Because of this, a discussion of the physical, physiological and psychological effects are presented with recommendation for incorporating all of these into the testing.

Physical Effects:

The transfer of heat from the body via the head is simply a function of the surface area available. Since the head is less than 10 % of the body surface area, the proportion of the total body heat loss by the head is relatively small. However, when chemical protective overgarments are worn the relative contribution of the head to total body heat loss increases as the other areas of the body are covered. Consequently, wearing the mask and hood over the head can seriously reduce the already limited heat loss capability of the body. In a study done by the U.S. Army (1974) with an air motion of $0.3 m \cdot s^{-1}$, the insulating air layer around a bare head was reported as 0.54 CLO units. The evaporative moisture permeability was 0.62 yielding a permeability index ratio (I_m/CLO) value of 0.97; which means sweat evaporation cooling from the bare head is only 3 % less than the maximum evaporative cooling capacity of the environment. When standard U.S. M-1 helmets were worn, the I_m/CLO value dropped to 0.43 indicating greater than a 50% reduction in heat transfer from the head.

Subsequently, an evaluation of the U.S. M17 mask alone and the M6 protective hood was conducted by Goldman (1984) to discriminate the heat stress effects of a protective hood from the heat stress effects of the mask. In still air, the standard U.S. helmet and M17 mask on a sweating sectional mannequin head yielded an I_m/CLO value of 0.13; with the addition of the impermeable M6 hood, the permeability index ratio decreased to 0.02 I_m/CLO. Assuming that a soldier is wearing a helmet, donning a mask without a hood can reduce heat transfer from the head by approximately 70 % and adding the hood can make the total decrease in heat transfer greater than 90 %. Furthermore, the M6 hood also covers the shoulders and seals the opening at the jacket's collar, thus reducing evaporative heat transfer from the torso by about 25 %. If the body is already having difficulty in maintaining its requirements for heat loss, this loss of heat transfer ability from the head and torso could result in significant increase in core temperature and decrease in work performance as a result of the increased body heat storage.

A soldier wearing a mask in direct sunlight may gain heat in the area of his/her face by the mask's greenhouse effect. Masks with large lenses or transparent facepieces collect more radiant energy. However, the ventilatory induced air motion within the mask attenuates this greenhouse effect. Heat gain via this pathway maybe a problem or at least a nuisance, during tasks requiring minimal movement and subsequently low ventilatory rate.

Physiological Effects:

Several studies have attempted to evaluate the effect of mask wear on the physiological responses during exercise in the heat. Robinson and Gerking (1945) studied two heat acclimated subjects for the effects of the masks on sweat rate, heart rate and body temperature in both hot/wet and hot/dry environments. In both environments the subjects wore jungle fatigues and exercised for two hours at 350 watts. Wearing a mask and impermeable hood elevated the sweat rate by about 28 % above the no mask and hood controls in the hot/wet environment and by about 16 % in the hot/dry environment. Mean skin temperature was increased, but core temperature was not further elevated when the mask and hood were worn. The heart rate tended to be higher with the mask on.

Other researchers have found that sweating under the mask and hood causes an uncomfortable accumulation of liquid which soaks the chin. Sweat often penetrates the filter elements in CD masks causing an increased inspiratory resistance and degradation of the filter's protective function. During development of clothing materials it would be beneficial to have an estimate of the thermal strain that could be expected. Although many experiments have been reported on the limits of tolerance of CD-clothing, the ever returning question is whether those results could be transferred to other materials for CD-protective clothing . Many parameters are involved here: heat resistance and water vapor permeability of the fabric, wind penetration, other clothing that is worn, the fit of the garment and the posture and motion of the wearer. No method has been published to date which relates the fabric data to experimental results on subjects. The usual procedure is that the measured thermal strain during a specific activity is correlated with the heat insulation as measured on a thermal mannequin and the vapor permeability as measured on a wetted flat plate (material sample). The correlation is purely mathematical; the actual insulation and vapor permeability during the activity, which may be considerably different from the static conditions, is unknown.

It has been attempted to acquire the actual insulation and vapor permeability data during the performance of the activity, not only for the whole assembly, but for the separate components as well. There are no acceptable data published for the clothing insulation and vapor permeability during task performance of clothing for which the fit of the garment must also be considered. The claim is only to provide a useful estimate of the significance of material properties.

Lotens came to the conclusion that the total heat storage in the body is the predominant criterion for heat tolerance, at maximum of nearly 8 J/g body weight. Therefore, it matters little whether overheating arises because of heat from the outside (hot skin) or heavy work (hot core). For heat and work, both the muscles and peripheral vascular system require blood supply. Since the muscles are greatly involved in the recirculation of the blood, this state can be maintained for some time, but with the stoppage of movement, there is an excess blood storage in the large veins and there is threat of fainting. The fainting from stoppage of movement occurs when body temperatures are $38^{0}C$ or higher. A closely related variant is the fact that the corresponding high heart rate has a tendency to continue to increase, even when the body temperature and work are stable. This goes hand in hand with the exhaustion phenomena. Therefore the TNO, Netherlands, has considered both heat storage and heart rate criterion.

The relationship between clothing, mask design and operational performance is a very complicated one and due to lack of control of some variables involved virtually impossible to assess. The results of experiments can be summarized by the rule of thumb that energy cost increases 4 % for each clothing layer at marching speed and 3 % per layer with a slower pace. It seems logical, yet unproven, that motion restriction does raise energy cost considerably.

Psychological Effects:

Aside from the actual physiological strain imposed by wearing the mask in warm environments, there exists the psychological acceptability of a mask in these environments. Factors such as the dry bulb temperature and dew point of the air inside the mask and facial skin wetness, affect the temperature and comfort sensations for the whole body. In a study by Gwosdow et. al., (1986), six subjects wearing ventilated masks during rest and exercise in a wide range of environmental conditions were asked to rate their whole body thermal sensation and perception of breathing effort. Increasing the dry bulb or dew point temperatures in the mask decreased whole body thermal acceptability. The whole body thermal sensations were directly correlated with upper lip skin temperature. The subjects perceived breathing to be more difficult with increasing intra-mask temperature and humidity. Protective mask acceptability and the capacity to perform essential military tasks may be severely degraded by the interaction of soldiers' psychological acceptability of the mask and the increased physiological strain due to mask wear. This points to the importance of temperature and humidity control when using microclimate cooling to ventilate the facepiece of the mask.

4.4.3 Recommendation

The JSOR does not provide the level of guidance required for the problem of thermal effects on soldier performance. It is obvious from this short discussion that the effects of heat and mask design on performance should receive more study than it has in the past. Some very basic questions are going unanswered and should be evaluated in detail to provide the best mask design to the soldier.

The Advanced Protective Systems Integrated Laboratory has a thermal chamber available. Unless this chamber proves to be ineffective, it is recommended that the thermal studies using human subjects be conducted in this chamber. The use of the Arm/Leg Ergometer (discussed in Respiratory Section) and the MedGraphics Metabolic Cart would provide a comparison with actual military tasks in hot/wet or hot/dry environments.

To model the effects of different clothing combinations with the mask it is recommend that the Heat Strain Model developed at ARIEM be used. This new model is based on the calculator-operated heat strain prediction model developed by the U.S. Army Research Institute for Environmental Medicine. The model can be used to determine the core temperature at various I_m/CLO, temperature, humidity and physical workload levels. The output is an equilibrium core temperature and time required to reach that temperature. This model is an excellent source for analyzing the effects of various mask and hood designs on human core temperature without the use of human subjects. Those mask designs which look most promising can then be tested using human subjects.

4.5 Personal Support

4.5.1 Requirement

As a minimum, the mask shall provide the wearer with a drinking capability from the canteen. The drinking device shall be capable of operating in temperatures above 32°F to a maximum of 120° F. The mask shall allow the intake of one quart of water within ten minutes. Water intake shall begin no more than 15 seconds following initiation of mouth generated sucking pressure. The time required to prepare the drinking device shall be no more than two minutes.

No requirement has been established for eating while wearing a protective mask. The Surgeon General has not accepted food intake in a chemical environment. The last work on the feeding through the mask was accomplished by Natick in 1987 (telecon-H. Miller) and has not been revitalized since then. Therefore, we did not look into the feeding procedures any further than to gain this information.

4.5.2 Test Method

The JSOR states subjects will be used to measure the preparation time and to obtain the required rate of water intake during field trials. Preparation time will be the time it takes a subject to detach the drink tube from the mask and properly insert it into the canteen drinking cap. The mask will be on the face and the canteen in its carrier at the start. The operations will be accomplished both with and without environmental and protective handwear, excluding Arctic mittens. The drinking device, when being operated (that is connecting and disconnecting to the canteen) in a contaminated environment, shall not cause facepiece leakage when tested against corn oil aerosol IAW procedures outlined in the vapor hazard section of the JSOR.

4.5.3 Recommendation

The testing of the drinking devices for respirators is straight forward. The only drawback is the subjective nature of the liquid intake tests. A flow rate device should be constructed to measure both time of water travel through the drinking device and the rate of liquid intake. These analyses and a subjective analysis test should be used to assess the overall compatibility of the device with the user. Since there are differences in drinking speed and esophageal response to swallowing liquid; the length, diameter and placement (location of the drinking tube and different methods of water intake) of the drinking tube requires more research before a time per liter can be determined.

4.6 Compatibility

4.6.1 Requirement

The mask shall allow the satisfactory use of standard optical devices, be compatible with the sights of individual and crew-served weapons, the head harness shall not cause pressure points and meet the comfort criteria. The comfort criteria state that trained soldiers shall be capable of wearing the mask for 12 hours while performing their assigned military duties under conditions of moderate work rate (undefined) and temperate climatic conditions. The total weight of the mask, carrier and mask accessories should be as light as possible, but shall not exceed 4.0 pounds.

4.6.2 Test Method

The most prevalent compatibility issue is with the optical sights on many weapon systems (Paicopolis, 1987). These sights rely on the position of the user's eye relative to the lens to present the desired sight picture. At the exit pupil of an optical sight, the field of view through the sight is maximized. As the distance between eye and sight increases, the field of view decreases. Current mask designs increase the eye to sight distance because the lenses are located at a distance from the eye to allow flowing air to defog the lenses. While the reduced field of view may not cause significant degradation in the accuracy of gunnery skills, the tasks of detecting and acquiring targets have demonstrated degradation. Estimating the loss in field of view can be accomplished using the Slogoff equation. This equation calculates the percent occlusion that occurs if the eye relief designed into the optical instrument (ER) were varied by some distance x, which is the distance from the front of the protective mask lens to the cornea. This varies as a function of fit for the wearer. The apparent field for the instrument used is 2β. When the protective mask is worn, the reduced apparent field of view is $2\beta^*$. The formula to determine the percent occlusion that results when the apparent field is reduced is:

$$\% \text{ Occlusion} = \frac{2\beta - 2\beta^*}{2\beta} \times 100$$

where 2β = magnification x field of view

and $2\beta^* = 2\tan^{-1}\left[\frac{EP+P}{x^2-ER^2}\right] - k$

where EP = exit pupil diameter
P = pupil size of 3 mm (0.117 in.)
k = constant vertical pupil aperture of 0.039 in.

This equation calculates the percent occlusion that occurs if the eye relief designed into the optical sight is varied by some distance. This distance is measured from the eye to the outer edge of the protective mask lens. Because the distance from the eye to the outer edge of the mask lens will vary based on fit and anthropometric data, a standard headform should be used to obtain this measurement.

Another area of concern is with the interface of mask and small arms. Sighting many small arms and crew-served weapons requires the soldier to rest his/her cheek on or very near the weapon to align the front and rear sights and obtain a proper sight picture. If the mask does not allow this, the rifle must be canted to obtain the sight picture. Twisting the rifle to the side creates an uncomfortable and unfamiliar body position for firing, which tends to reduce accuracy.

4.6.3 Recommendations

Compatibility, comfort, and fit requirements are typically verified through human task performance testing. Subjects don the mask and perform normal tasks. Observation of subjects and test subject comments identify performance degradation areas caused by the mask. Also, during mask design/development, compatibility, comfort and fit concern areas can be addressed and many problems alleviated.

The JSOR states that the mask shall be designed so that the mask can be donned, whether standing, sitting, kneeling or lying prone within 9 seconds by properly trained personnel. This mask characteristic can only be measured by training personnel in the proper procedures for donning the mask and timing their performance.

An important aspect in evaluating protective mask performance is determining how well the mask fits and provides protection from agent liquids, aerosols, and vapors. The quantitative fit factor (QFF) is found to determine how well a given mask protects the wearer. QFF is defined as the aerosol concentration of agent outside the mask (c_o) divided by the concentration measured inside the mask (c_i):

$$QFF = \frac{C_o}{C_i}$$

Ideally, this quantity approaches infinity for a perfectly fitting mask. However, real masks provide QFFs ranging from 1,000 to 100,000 for chemical agent protection and can exhibit significantly different QFFs between masks of the same make and even between fittings of one mask on one person. These variances are caused by two major problems: it is difficult to don masks in a consistent manner, and due to variability in head shapes and facial features, masks designed to fit a range of head/face sizes will not always fit correctly. To further complicate matters, wearers must be able to perform normal functions while wearing the mask. Normal functions include bending the neck and talking/shouting, both of which tend to break mask face seals. These factors make determining an accurate QFF of the mask very difficult. In fact, the NIOSH Guide to Industrial Respiratory Protection states that no data have been reported to demonstrate that measured values of QFF are indicative of a respirator's performance in actual use.

Many methods for evaluating fit factors of respirators have been used in the past, but these methods vary in apparatus, challenge aerosol, measurement equipment/technique, etc. Data collected by different methods do not produce consistent results for a given mask. The respirator community of the United States military recognized the variability in determining QFF and although they could not eliminate the physical differences found among military personnel, they could develop a methodology to at least standardize the equipment, testing methodology, measurement equipment, and QFF determination. The United States Joint Service Standardization Agreement for Fit Factor Testing of Military Masks (provided in Appendix B) is the result. The agreement is approved and required for standardized fit factor testing by the U. S. Army, Air Force, Navy and Marine Corps.

The United States Joint Service Standardization Agreement for Fit Factor Testing of Military Masks standardizes several areas of fit factor testing. The desired system is a corn oil aerosol test system with a concentration range and Mass Mean Aerodynamic Diameter (MMAD) range as defined in the standard. A specific number of test subjects perform a set of defined exercises (depending on the mask application) in a chamber. Samples are taken with a light scattering photometer in the eye region. The standard defines how and when data are collected and reduced. Although the standard is specific about several parameters, developers can deviate from the standard as long as the modified system is properly correlated to the standard system. For example, corn oil is difficult to remove from the test apparatus, so some systems generate salt fog. This is acceptable if the salt fog results have been properly correlated to corn oil results.

Other methods are available for less formal fit testing, usually including a simple hood and a smell solution that can be identified by the test subject upon breakthrough. Table 6 lists equipment and costs which are available to test mask protection, respiration and seals.

Table 6. Mask Protective Seal Evaluation Equipment

Company	Item	Description	Mask Characteristic Evaluated	Estimated Cost (dollars)
Shoes and Gloves (3M) (614) 885-8029	KIT #FT10	Larger than head hood, sensitivity/smell solution, fit test solution	Protection/Seal	132
Shoes and Gloves (3M) (614) 885-8029	KIT #FT20	Larger than head hood, sensitivity/smell solution, fit test solution, training videotape and case for kit.	Protection/Seal	280
Test Engineering Tom Reed (707) 445-3680	Custom	Custom breathing machines can be built based upon modification of NIOSH approved breathing machine plans.	Breathing Resistance	~6,000
BioSystems, Inc. (203) 344-1079	POSI-CHECK	Breathing machine capable of measuring seal protection, breathing resistance. Seal protection is determined with a vacuum leakage test. Exhalation valve opening pressure can be measured. Face piece pressure can displayed as a function of time or simulated tank pressure.	Protection/Seal, Breathing Resistance	10,000
TSI (distributed by Instrumentation System, Inc.) Steve Snell (513) 294-2838 or (216) 845-8800 (412) 823-7005	#8020 Porta Count Plus	Respirator fit tester. Operable as stand alone test set-up or with FITPLUS IBM compatible software. Digital display, dBASE data format, printing capability.	Fit factor	7,000
TSI	#8110 Certi Test Automated Filter Tester	Ability to test HEPA grade 99.97% efficiency. Designed to meet current particulate filter respirator certification standards.	Filter Performance	29,000
TSI	#8111 accessory for #8110	Provides fit testing with challenge aerosol, easy selection of sampling times, purge times, aerosol types.	Filter Performance	2,400
TSI	#8140	Ability to test for high efficiency particulate filter cartridges (99.999999% efficient). Uses two clean room condensation nucleus counters, adjustable flow rates.	Filter Performance	54,400
TSI	#8160	Like #8140 except additionally provides determination of complete efficiency versus particle size curve (generates various sized particles)	Filter Performance	114,200
TSI	#8091 Certi Test Automated Respirator Tester	Completely programmable respiration machine and automated breathing simulator. Breathing rates/patterns are adjustable.	Breathing Resistance	12,500
TSI	#8120	Designed to allow true simulation testing with various breathing rates and challenge aerosols. Can test filter cartridges and media like #8110. #8091 is integrated to this unit.	Breathing Resistance	81,500

4.7 Psychological

4.7.1 Requirement

No JSOR has been established regarding the psychological aspects of protective equipment.

4.7.2 Test Method

Since no requirement exists for the psychological testing, data are presented as to reasoning for testing and available methods and equipment to accomplish the testing. No substitute (psychological simulation) for human subjects is available for the psychological testing.

Approximately 10 % of the soldiers *volunteering* to participate in field or lab studies are found to have psychological problems such as, anxiety or depression, and these disturbances range from mild to those which are regarded as clinically significant. The degree of psychopathology has been observed to correlate inversely with perception of effort, CO_2 sensitivity and work tolerance. All cases of breathing distress associated with respirator wear are not necessarily the result of psychological problems, since it has been reported that peak respiratory flow rates may exceed the delivery capacity of the respirator.

The manifestations of an anxiety attack while wearing a mask include the psychophysiological consequences of hyperventilation, which can lead to decrements in military task performance. Hyperventilation can produce symptoms including dyspnea, tachycardia, dizziness, blurred vision, paresthesia, trembling and tetany; full-blown attacks can result in convulsions and disturbance of consciousness. Psychomotor performance is impaired by hyperventilation; the degree of psychomotor deterioration appears to be inversely related to the alveolar PCO_2. In most individuals, hyperventilation does not manifest all these symptoms. However, some individuals are apparently more sensitive to the effects of hyperventilation. Individuals possessing this sensitivity are characterized as susceptible to the hyperventilation syndrome; such individuals may be more prone to experience respiratory distress while wearing a mask and performing physically demanding military tasks.

Psychological discomfort of wearing the mask depends on a number of factors. Some of these have been studied such as: pressure points of the head and face, sensations of breathing difficulty, temperature and humidity inside the mask, or limits on vision, speech and hearing. Additionally, there is the individual's perception of the degree of stress each of these factors has on his/her performance. Morgan and Raven (1985) tested the hypothesis that an individual's likelihood of experiencing distress when exercising while wearing a mask could be predicted from their level of trait anxiety. They tested 45 male subjects by first administering Spielberger's Trait Anxiety Scale and then giving three submaximal exercise tests while the subjects wore a self contained breathing apparatus. Spielberger's model of trait anxiety predicts that high scoring individuals would be more likely to experience anxiety attacks when performing physically hard work while breathing through a mask. Morgan and Raven predicted that subjects with trait anxiety scores one standard deviation or greater above the group mean would experience respiratory distress during the exercise while wearing the breathing apparatus. The results confirmed their hypothesis. Based on the trait anxiety scores, the "hit" rate for predicting distress was 83 % and their accuracy for predicting no respiratory distress was 97 %. These results demonstrated that anxiety was effective in predicting the development of respiratory distress during exercise while wearing a breathing apparatus.

It is also recognized that breathing is difficult, ventilation across the face is limited, movement is restricted because of the cumbersome nature of most equipment and wearing a respirator adds to the energy cost of exercise, which in turn accentuates the effect of working in a hot environment. Douglas (1986) pointed out the problems caused by improper fitting causes "pain spots" that can become intolerable. An improperly designed valve may restrict breathing or irritate the wearer by flicking and popping. Communication is restricted and can add to existing hazards in a combat environment.

A series of studies accomplished by the U.S. Army assessed the capability of soldiers to conduct sustained military field operations while wearing full chemical clothing ensemble. The 81 soldiers were administered a battery of psychological tests prior to and after the field operations. Soldiers who failed to complete the 72-hour operation were classified as "casualties". The single symptom which maximized the difference between the survivors and casualties was that the latter quit because it "hurts to breathe". Consequently, the perception of respiratory discomfort could compromise the performance of military operations.

All physiological problems associated with respirator wear were rather minor in comparison to the psychological response (Shepard, 1962). It has been shown that subjective tolerance to the respirator was influenced primarily by pressure exerted during inspiration. This finding provides a possible clue to understanding the breathing problems encountered by some individuals when wearing respirators. Even though 75 to 90 % of a given population would not experience discomfort at a given pressure, it would not be uncommon for certain types of individuals to experience anxiety attacks under identical circumstances. Davies, in *Design and Use of Respirators* summarizes the major problems associated with respirator wear. Davies emphasizes that modern filters and absorbers are very effective, but the main limitations of a respirator are facepiece leakage, breathing resistance, poor speech, impaired vision and discomfort. According to Astrand and Rodahl ventilation increases in a fairly linear fashion with increasing work load, but the slope of this function becomes much steeper during heavy work loads. The basis for this increase in ventilation at higher work loads is not entirely understood. The relatively small changes in PO_2, PCO_2 and hydrogen ion concentration in the arterial blood cannot explain the hyperventilation observed in heavy work. The psychophysiological consequences of hyperventilation are well known, and this state will lead to performance decrements and extreme safety risks. In other words, heavy exercise per se produces hyperventilation and there is evidence suggesting that wearing a respirator accentuates the hyperventilation response.

4.7.3 Recommendation

A method to study psychological effects of the mask has been developed by the U. S. Air Force. It was designed primarily for aviation studies, but was developed under a Joint Working Group for Performance Degradation in Chemical Environments with the U.S. Army as the program manager. Since the same methods for psychological studies are still in effect for mask design study this automated method lends itself to the mask study environment at the Advanced Protective Systems Lab. The Performance Assessment Test System (PATS) has the capability to collect, reduce and analyze psychological and physiological data. This procedure would allow for a controlled study of the mask-human interface, which to date does not exist. The following tests are available with PATS:

Cognitive Tests	Sensory Tests	Continuous Tests
Rare Event	Checkerboard	EEG
Memory Scanning	Unpatterned Steady State	Eyeblink
Continuous Performance	Brain Stem Evoked Response	Respiration
Display Monitoring	Somatosensory	Heart Rate
Tracking		EMG
Simple Flash		
Custom Tests		

The PATS will be available on the MacIntosh II and is designed to use off-the-shelf hardware components. The PATS uses a menu format featuring a flexible navigational route which does not restrict the user to a specific order of operations. Different tests can be run simultaneously, with 16 channels available. Data reduction is available to extract the relevant data for analysis and prepare it for statistical analysis, using a resident statistical package which allows for descriptive and inferential statistics with graphing capability. The Point of Contact for this system is Dr. Glenn Wilson at (513) 255-8748, the PAT system can be purchased from the USAF for $200.00. Using the PATS with the respiratory and workload equipment may provide a superior picture of the interaction of the protective mask and soldier performance than has been available in the past.

5.0 Conclusions

The objective for this study was to identify and describe, in detail, all special equipment needed to conduct the tests of the given subcategories (vision, communication, etc.). Then propose approaches for development of special equipment and the estimated costs of the equipment and estimate suitable requirements for each of the degradation tests identified. We have succeeded in accomplishing this task.

Other objectives were met completely or in part. Battelle provided data on tests and equipment which will provide quantitative assessments of degradation, selected equipment which will provide repeatable comparisons, where possible, we have isolated each degradation category and eliminated the human variability. The test methods are designed to identify the critical parameters for each degradation subcategory.

6.0 Recommendations

The JSOR requirement and the associated recommendation are summarized for each subcategory discussed in the body of this report.

6.1 Vision

6.1.1 Luminous Transmittance Requirement

The luminance transmittance shall be equal to or greater than 85 %.

Recommendation

The listed test methods are capable of providing non-subjective, quantitative evaluations of protective lens. ANSI Z87.1, MIL-V-43511 and CSA-Z94.3 all advocate the use of a spectrophotometer. Future battlefield threats may include lasers with wavelengths outside of the visible region. The wider range in wavelength monitoring capability of the spectrophotometer may prove useful when future threats become realized.

6.1.2 Haze Requirement

Haze shall be less than or equal to 5 %.

Recommendation

The GardnerHazemeter is recommended and should be capable of providing quantitative and repeatable results.

6.1.3 Vertical Prismatic Deviation Requirement

Vertical/horizontal prismatic deviation shall not exceed 0.18 diopters. The algebraic sum and difference of the horizontal deviation between the two center points must not exceed 0.50 and 0.18 diopters respectively.

Recommendation

Both the lensometer and focimeter type instruments are capable of providing quantitative and repeatable results. New automated lens analyzers, such as the Humphery Lens Analyzer, can not only measure prism deviation but also refractive power and cylinder.

The focimeter (i.e., the Vertometer of Reichart Optical) is subjective and may reduce the reliability of the data. The easiest method of measuring prism, refractive power and cylinder is the Humphery Lens Analyzer system. This system is compact and automated and should provide non-subjective repeatable measurements.

6.1.4 Refractive Power Requirement

The refractive power of the lens shall be less than or equal to 0.125 diopters.

Recommendation

The automated Humphery Lens Analyzer is capable of measuring prism, refractive power and cylinder.

6.1.5 Distortion/Definition/Astigmatism Requirement

Distortion shall be subjectively compared to the distortion standards shown in Figure 1 of Mil-V-43511B.

Recommendation

The were no quantitative (non-subjective) methods of measuring distortion identified. The Ann Arbor optical tester should provide adequate distortion assessments of protective masks.

6.1.6 Peripheral Field-of-View Requirement

No requirements presented.

Recommendation

The use of the Alderson 50th percentile male head form in the goniometer should be capable of providing quantitative and repeatable results. These results should be useful in FOV comparisons between different mask types.

The most important issue to confront is the lack of requirements for peripheral FOV in the JSOR. In fact, out of the four standards reviewed, only the CSA contained FOV requirements. Further testing may be necessary to substantiate the FOV requirements. FOV requirements must be established.

6.1.7 Reflecting Glare and Glint Requirement

No established criteria.

Recommendation

Requirement must be defined before an appropriate test method can be identified.

6.1.8 Shatter Resistance Requirement

There shall be no lens fractures or object penetration.

Recommendation

Both the ANSI Z87.1 and the CSA-Z94.3 test methods are well described and should provided reliable and reproducible results for high mass impact tests. MIL-STD-662 should be followed to provide high velocity impact results. It is recommended that the high mass testing methods in ANSI Z87.1 and high velocity testing methods in MIL-V-43511 both be used.

6.2 Communications

Requirement

The mask shall permit intelligible voice transmission (face to face) and shall not interfere with hearing. It shall permit the use of receiving and transmitting communication devices currently in use by the services, those now in development and those in use at the time of the new mask availability.

Recommendation

Mil-Std-1472D states the 75% MRT level should not be used for operational equipment. The NATO standard of 85% MRT should be considered as the standard. Using the NATO standard will require redesign of the voicemitter and/or the use of an auditory system to assist the soldier in the field.

It is recommended that since a large monetary investment would be necessary to provide the facilities already available at the USAF Biodynamics and Bioengineering Lab that CRDEC send any masks requiring this specialized testing to the US Air Force.

6.3 Respiration

Requirement

Inhalation breathing resistance shall be no greater than 55 millimeters (mm) of water at 85 liters per minute (lpm) for the field version of the mask and no greater than 70 mm of water at 85 lpm for the aviation and combat vehicle masks with attached hoses. Exhalation breathing resistance shall be no greater than 26 mm of water at 85 lpm. Under normal activity, (undefined) effective dead space shall not exceed 400 ml.

Recommendation

The research points to the development of tests which closely mimic specific tasks of the soldier's work environment. For a total understanding of the workload imposed on the human an arm/leg ergometer is recommended. If an arm/leg ergometer is not feasible, then the leg ergometer is recommended.

With the ergometer (or treadmill) the Medgraphics Metabolic Cart is recommended to collect data on aerobic, metabolic, cardiopulmonary and thermal responses.

Masks should be tested by sealing the mask on an Alderson 50% headform and simulate breathing. Human breathing is simulated in a sinusoidal pattern with pressure transducers mounted to measure pressure drops during the entire breathing cycle. This type of evaluation allows for a better simulation of actual wear of the mask including flows inside the mask and interference with facial features or mask structures than with constant flow evaluations.

The inhalation and exhalation resistance should be kept to the minimum yet protect against seal leakage. The design goal should be to develop a mask which has all of the protection components, yet when the soldier dons the mask there is very little change in breathing resistance. This is difficult to

accomplish, but the least amount of resistance which will properly seal the mask is recommended from the physiological and psychological position of the soldiers.

The amount of breathing resistance which is described as being physiologically first detectable at 10 mm H_2O at 100 lpm, first observable at 8.7 mm H_2O and 100 lpm, tolerable at 15 mm H_2O and total breathing resistance should be kept at about 12 - 17 mm H_2O with inspiratory resistance of 6 -14 mm H_2O. Further testing will be required to substantiate these numbers. Other than laboratory experiments, the effects on actual soldier performance of different combinations of resistance have not been studied. Most studies examine the combined effect on soldier performance of the protective mask and clothing system, therefore it is difficult to tease out of the studies degradation due to just the breathing resistance of the mask.

Filter Capacity Recommendation: The filter design imposes degradation on the soldier which requires further study. The best filter would be one which contains a sensor which recognizes the gases in the air, analyzes them and increases or decreases the protection level to protect the soldier when in a contaminated environment and when not in a contaminated environment the filters remain essentially non-existent.

A recommendation for agent testing of the mask is the use of a sinusoidal breathing system which challenges the entire mask including the filter with live agent or simulant. Exhalation contamination, bi-directional flows, human interface and realistic challenge should be simulated to provide correlational results.

Dead Space Recommendation: The portion of the population with CO_2 sensitivity is between 2 and 5 %, this group has not been studied in depth using changes in a combination of heavy work, dead space and breathing resistance to determine if the change in dead space would affect a large enough sample to be beneficial. Any change in dead space would also need to be studied concerning the psychological effects of moving the respirator closer to the face and what effect the thermal response to this change would be. The amount of sweating may not permit moving the nose cup closer to the face. There are a number of interactions which must be studied before changes in nose cup design can be made.

6.4 Thermal

Requirement

The operational temperature range as between 25^{0}F to 120^{0}F. There shall be no degradation in performance during wear within the temperature range. The criteria for performance of common military skills, as modified for the temperature environments, shall apply. Methods defined in the test agency's test design plan will be utilized.

Recommendation

The JSOR does not provide the level of guidance required for the problem of thermal effects on soldier performance. It is recommended that the thermal studies using human subjects be conducted in this chamber. The use of the Arm/Leg Ergometer (discussed in Respiratory Section) and the MedGraphics Metabolic Cart would provide a comparison with actual military tasks in hot/wet or hot/dry environments.

To model the effects of different clothing combinations with the mask it is recommend that the Heat Strain Model developed at ARIEM be used.

6.5 Personal Support

Requirement

As a minimum, the mask shall provide the wearer with a drinking capability from the canteen. The drinking device shall be capable of operating in temperatures above 32°F to a maximum of 120° F. The mask shall allow the intake of one quart of water within ten minutes. Water intake shall begin no more than 15 seconds following initiation of mouth generated sucking pressure. The time required to prepare the drinking device shall be no more than two minutes. No requirement has been established for eating while wearing a protective mask.

Recommendation

A flow rate device should be constructed to measure both time of water travel through the drinking device and the rate of liquid intake. These analyses and a subjective analysis test should be used to assess the overall compatibility of the device with the user. The length, diameter and placement (location of the drinking tube and different methods of water intake) of the drinking tube requires research.

6.6 Compatibility

Requirement

The mask shall allow the satisfactory use of standard optical devices, be compatible with the sights of individual and crew-served weapons, the head harness shall not cause pressure points and meet the comfort criteria. The comfort criteria state that trained soldiers shall be capable of wearing the mask for 12 hours while performing their assigned military duties under conditions of moderate work rate (undefined) and temperate climatic conditions. The total weight of the mask, carrier and mask accessories should be as light as possible, but shall not exceed 4.0 pounds.

Recommendation

Compatibility, comfort, and fit requirements are typically verified through human performance testing. Subjects don the mask and perform normal tasks. Observation of subjects and test subject comments identify performance degradation areas caused by the mask. Also, during mask design/development, compatibility, comfort and fit concern areas can be addressed and many problems alleviated.

6.7 Psychological

Requirement

No JSOR has been established regarding the psychological aspects of protective equipment.

Recommendation

The Performance Assessment Test System (PATS) has the capability to collect, reduce and analyze psychological and physiological data. This procedure would allow for a controlled study of the respirator-human interface, which to date does not exist

Glossary

Diopters: 1/focal length in meters. A 0.125 diopter lens has a focal point of 8 meters (26.25 feet) which is slightly beyond optical infinity for the eye.

Distortion/Definition/Astigmatism: The apparent waviness or irregular displacement of an object when viewed though different areas of a lens. Astigmatism is a condition in a lens in which there is a difference in refractive power in one meridian form than in another meridian.

Haze: The percent of transmitted light which in passing through the specimen deviates from the incident beam by forward scattering. For the purpose of the test method ASTM D 1003-61 only, light flux deviating more than 2.5° on the average is considered to be haze.

Luminous Transmittance: The ratio of transmitted to incident light (IAW ASTM E 308).

MRT: Modified Rhyme Test.

Peripheral Field-of View: The area in which an image is rendered by the eye. The horizontal/vertical boundary within which the eye can perceive an object.

PCO_2: Pressure of Carbon Dioxide in the blood stream.

PO_2: Pressure of oxygen in the blood stream.

QFF: Quantitative Fit Factor.

Refractive Power: The ability of a transparent media to converge or diverge light rays to a real or virtual focus. A measure of the of a lens to focus light rays, expressed in diopters.

Shatter Resistance: An impact due to hits on the target (lens) by projectiles, fragments of other aerodynamically-affected threat mechanisms. Ballistic resistance in a measure of the capability of a material (lens) of component to stop or reduce the impact velocity and mass of an impacting projectile of fragment.

Vertical Prismatic Deviation: Non-flat and parallel optical surfaces cause a deviation in a beam of light towards the direction of the thicker area of the lens. Prism power is a measure of the angular deviation expressed in prism diopters of a light ray after passing along the design viewing path through the lens.

References

American National Standard Practice for Occupational and Educational Eye and Face Protection (ANSI Z87.1-1989). American National Standards Institute, Inc., 1430 Broadway, New York, New York, 10018.

Cotes, J. E. (1962). Physiological aspects of Respirator Design. In C. N. Davies (ed.) Design and Use of Respirators. New York: MacMillan.

Deppisch and Craig as reported by Froehlich, H. L. (1966). Physiological Evaluation of a Modified M6 Protective Hood. Edgewood Arsenal, MD: U.S. Army Medical Research Laboratory.

Douglas. (1986). Customer test of M-17 series improved head harness (TRADOC TRMS No. 50000 656). Ft. Knox, KY: US Armor and Engineering Board.

Fonseca, G. F. (1974). Heat transfer properties of military protective head gear. Tech. Rpt. 74-29, U.S. Army Research Institute of Environmental Medicine, Natick, MA.

Goldman, R. F. (1984). Biophysical evaluation of relative heat stress of four chemical protective mask/hood systems. Rpt. C-028/MT21-84, Multi-Tech Corp., Natick, MA.

Gwosdow, A .P., R. Nielson, L. E. Berlund and A. B. Dubois. (1986). Comfort and acceptability of respiratory protection devices as affected by temperature and humidity. In Proc. American Industrial Hygiene. Association. Dallas, pps. 41-42.

Holewijn, M. (1987). Loss of performance due to NBC Protective clothing and equipment. TNO Institute for Perception.

Industrial Eye and Face Protectors - Occupational Health and Safety - A National Standard of Canada, CAN/CSA-Z94.3-M88, July 1988.

Johnson, A. T. (1990). Respirator Performance Rating Table for Mask Design. Advanced Protective Systems Integration Laboratory, Chemical Research, Development and Engineering Center, Aberdeen Proving Ground, MD

Joint Services Operational Requirement Approved Evaluation Criteria and Values and Approved Evaluation Conditions and Procedures (Revised JSOR, 21 1985).

Lotens W. A. (1982). Clothing design and its relation to military performance, Institute for Perception. National Defense Research Organization TNO, Thermophysiology, November 1982

Lotens, W. A. (1987). Thermal stress due to NBC protective clothing. TNO Institute for Perception.

Lotens, W. A., Havenith, G., Wammes, L. J .A. (1988). Prediction of thermal discomfort of CW-assemblies based on fabric measurements. IZF TNO Institute for Perception.

Love, R. (1980). Acceptable Breathing Resistance for Respirator Use. In NIOSH International Respirator Workshop.

Military C-83409: Coatings, Visor, Polycarbonate, Flying Helmet. 14 March, 1986.

Military S-44366A: Spectacles, Protective, Laser, Ballistic. 30 June 1989.

Military S-25948J: Sunglasses, HGU - 4P (with Case). 28 August 1986.

Military V- 43511C: Visors, Flyer's Helmet, Polycarbonate. 16 July, 1990.

Military V- 22272D: Visor, Neodymium Laser, Protective for Aircrewman's Helmet. 24 October, 1991.

Military V- 85374: Visors, Shatter Resistance. 9 January 1981.

Military STD- 662D: V50 Ballistic Test for Armor. 19 March 1984.

Morgan, W. P. (1983). Psychological problems associated with the wearing of industrial respirators: a review. American Industrial Hygiene Association, J 44(9) pps. 671-676.

Morgan, W. P. (1983). Psychological problems associated with the wearing of industrial respirators: A review. Los Alamos Scientific Laboratory, Los Alamos, NM.

Morgan, W. P. and P. B. Brown. (1985). Prediction of distress for individuals wearing industrial respirators. American Industrial Hygiene Association, J. 46:363-368.

Morrisette, J. W. and Paicopolis, P. (1991) Human factors in protective mask design: design handbook. U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD 21005-5001, February, (Draft Copy).

Optical Laboratory Technician, FM 8-37, 30 August 1976.

Robinson, S. and S. D. Gerking. (1945) Heat stress imposed by gas masks. (Report 26), Office of Scientific Research and Development, U.S. War Agency, Washington, D.C.

Shepard, R. J. (1962). Ergonomics of the respirator. In Davies, C. N., (ed.). Design and Use of Respirators (pps. 51-66) New York: MacMillan.

Van de Linde, F. J .G. (1987). Tolerance times and work-rest schemes for work in NBC protective clothing, pps. 8-14.

Tests for Motor Vehicle Lighting Devices and Components - SAE J575, July 1983.

Standard Test Method for Haze and Luminous Transmittance of Transparent Plastics, ASTM D 1003-61, (Reapproved 1988).

Appendix A

Equipment Manufacturers

COMPANY	ADDRESS	CITY	STATE	ZIP
American Bristol Industries	1600 West 240th Street	Harbor City	CA	90710
Asbestos Control Technology	P.O. Box 183	Maple Shade	NJ	08052
Atlas Copco Turbonetics	20 School Road	Voorheesville	NY	12186
Bauer	1328 Azalea Garden Drive	Norfolk	VA	23502
E. D. Bullard Co.	2680 Bridgeway	Sausalito	CA	94965
Consumer Fuels, Inc.	7250 Governors Drive West	Huntsville	AL	35805
Critical Services, Inc.	2828 Broad	Houston	TX	77087
Control Resource Systems, Inc.	670 Mariner Drive	Michigan City	IN	46360
Ingersol Rand	11 Greenway Plaza	Houston	TX	77046
Joy Manufacturing Co.	Montgomery Industrial Park	Montgomeryville	PA	18936
3M Company	3M Center Building 230-B	St. Paul	MN	55101
Daboco, Inc.	3319 E. Ten Mile	Warren	MI	48091
Davey Compressor Co.	11060 Kenwood Road	Cincinnati	OH	45242
Deltech Engineering, Inc.	Century Park, P.O. Box 667	New Castle	DE	19720
Dynamation, Inc.	3748 Plaza Drive	Ann Arbor	MI	48104
Dynatech Frontier, Inc.	5655 Kircher Blvd. NE	Albuquerque	NM	87109
Enmet Corp.	2307 South Industrial Highway	Ann Arbor	MI	48104
Hankison Corp.	1000 Philadelphia Street	Cannonsburg	PA	15317
Industrial Pump & Compressor	12014 Chain Lake Road	Snohomish	WA	98290
Industrial Safety Products	1502 Telegraph Road	Mobile	AL	36611
Rix Industries	6460 Hollis Street	Emeryville	CA	94608
Sullair Corp.	3700 East Michigan Blvd.	Michigan City	IN	46360
Mine Safety Appliances Co.	600 Penn Center Blvd.	Pittsburgh	PA	15235
National Draeger	101 Technology Drive	Pittsburgh	PA	15235
North Safety Equipment	2000 Plainfield Pike	Cranston	RI	02816
RhineAir, Inc.	8402 Magnolia Avenue	Santee	CA	92071
Racal Airstream, Inc.	7209A Grove Road	Frederick	MD	21701
Vortec Corp.	10125 Carver Road	Cincinnati	OH	45242
Willson Safety Products	P.O. Box 622	Reading	PA	19603

Appendix B

Fit Test Methods

UNITED STATES JOINT SERVICE STANDARDIZATION AGREEMENT
FOR
FIT FACTOR TESTING
OF
MILITARY MASKS

1 October 1991

TERMS OF AGREEMENT

1. Objective. To define a standard fit factor testing method to be used among all Services. This standard shall be used to determine the quantitative fit factor afforded to the respiratory tract and eyes by developmental or fielded military Nuclear, Biological and Chemical protective mask systems.

2. References. Air Standardization Coordinating Committee Agreement (ASCC) 61/14A Feb. 88.

3. Agreement. This agreement constitutes a declaration to conform to the provisions expressed herein. No departure therefore, will be made by any participant without prior consultation with all members.

4. Subscription by Other Services. The U.S. Army, the U.S. Navy, the U.S. Air Force, and the U.S. Marine Corps subscribe to this standard.

5. Protection of Proprietary Rights. This restriction concerning the release of technical information as result of this standard should be clearly indicated by all services or any individuals on releasing the whole or part of the information for any purpose whatsoever.

6. Reservations. None

1.0 Title: United States Joint Service Standardization Agreement for Fit Factor Testing of Military Masks.

2.0 Introduction:

2.1 The purpose of this test is to quantitatively measure the overall leakage of fielded or developmental military masks for the determination of the fit factor performance. It may also be used to assess mask fit degradation, if any, due to changing the canister or other mask components.

2.2 The performance of a mask system is commonly measured in terms of a fit factor which is expressed as the ratio of the challenge concentration of a substance outside a mask to the concentration measured within a mask during a given period of time. The term fit factor used in the context of this standard is meant to reflect in quantitative terms the quality of the face seal that an individual has obtained in a set of standard laboratory conditions.

2.3 Reproducibility of the fit factor results are difficult due to the variable test conditions and various human factors. The fit of the mask, therefore, shall be determined under the set of conditions specified in this standard so that mask performance can be more accurately compared by all the Services.

3.0 Standard Reference Test Equipment and Aerosol:

3.1 A corn oil aerosol test system, generally in accordance with Figure 1, shall be used. It consists of an aerosol generator, an air dilution blower, test chamber, sampling system, photometer detection system, and data collection system.

3.1.1 A light scattering photometer, capable of accurately measuring fit factors of at least 20,000, shall be used to measure the aerosol challenge/leak concentration.

3.1.2 Generally, the aerosol generating system consists of a source of clean, dry laboratory compressed air, pressure regulator and gauge, aerosol impactor, mixing plenum and dilution room air to control the aerosol. The challenge aerosol (test chamber atmosphere) is produced by atomization of the corn oil contained in a generator's reservoir at room temperature. When the compressed air enters the aerosol generator, a coarse aerosol is produced by high-velocity air jets that shear off droplets of the corn oil. The aerosol then enters the impactor column which removes the larger particles, thus producing an aerosol within the desired particle size range. Once the aerosol passes through the impactor, it is mixed with room make-up air.

3.2 The test challenge shall be a non-toxic corn oil aerosol approved for human use.

3.2.1 The test chamber aerosol concentration shall be between 20 and 40 Mg/m3 with Mass Median Aerodynamic Diameter (MMAD) of 0.4 to 0.6 um. The geometric standard deviation shall be less than 2.0. The test chamber shall be capable of maintaining spatial uniformity within +/- 5 % in the vicinity of the respirator being tested. The challenge aerosol concentration shall not vary as a function of time more than +/- 10 % over the duration of a single test (approximately 15 minutes).

SCHEMATIC DIAGRAM OF CORN OIL TEST APPARATUS

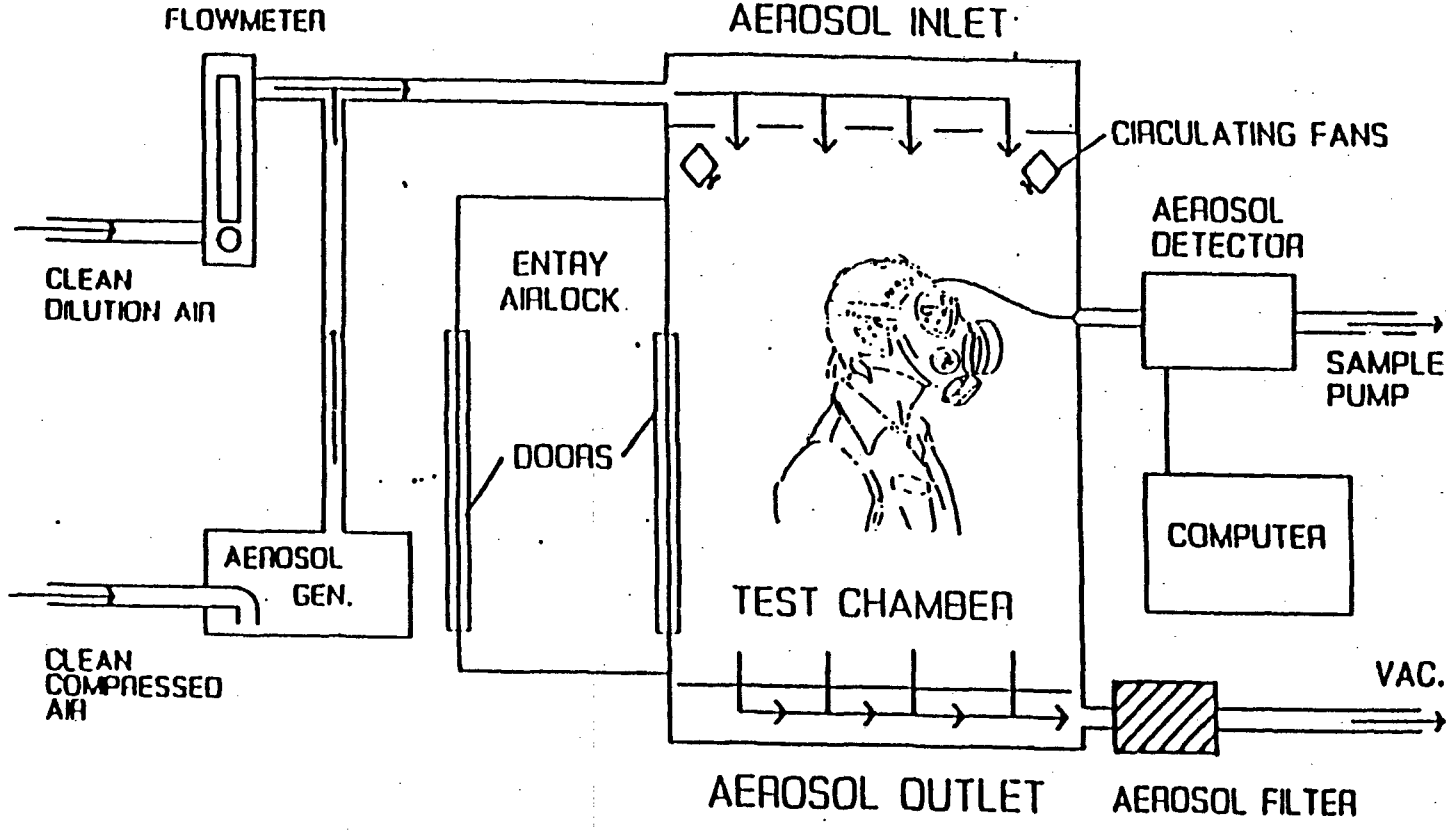


Figure 1

3.2.2 The aerosol challenge shall be characterized to verify that the aerosol is within physical parameters specified in para. 3.2.1. Typical calibration procedures for the aerosol characterization equipment are provided in Appendix A.

3.3 The standard reference sampling rate shall be one liter per minute per sample location.

4.0 Test Conditions and Procedures:

4.1 Human test subjects shall be representative of the Services' anthropometric distribution. Test subjects shall be selected based upon the Services' requirements for the mask system being tested. At a minimum, the anthropometric measurements, face length (Menton-Nasal Root Depression or Menton-Sellion) and face width (Bizygomatic diameter) shall be taken for mask size determination. In addition, neck circumference shall be recorded for systems that use a neckdam or second skirt.

4.2 The masks shall be properly sized and fitted on clean-shaven human test subjects. The use of expert, assisted, and unassisted sizing/fitting/donning techniques will depend on the specific test objectives. Expert assisted sizing/fitting/donning procedures shall be the primary method.

4.3 Testing shall be conducted using a minimum of 32 subjects.

4.4 An exercise routine intended to stress the face seal and approximate field use conditions shall be used. Each exercise shall be performed for one minute in duration.

4.4.1 A standardized set of core exercises shall be used to evaluate the two major mask categories, aircrew and non-aircrew. These core exercises shall be performed in sequence as shown in Table 1, paragraphs 1.0 and 2.0.

4.4.2 Additional exercises can be performed following the core set. The number, type and sequence of these optional exercises can vary depending on the type of mask system being evaluated and specific test objectives. Examples of a few of the more commonly used exercises are listed in Table 1, paragraph 3.0.

4.4.3 Specific unique core exercise sets may be needed to properly evaluate a given mask system. Use of a non-standard exercise routine shall be coordinated and agreed upon with the Joint Services and user representatives.

4.5 Human test subjects shall wear appropriate uniforms and individual protective garments, based upon the Services' requirements and test objectives.

4.6 The quality assurance tests shall be performed on the mask systems prior to and at the conclusion of the evaluation. The quality assurance (QA) test procedures for the U.S. Army Mask Systems will be issued by the U.S. Army, CRDEC. Other Services will provide QA procedures for their mask systems.

4.7 The primary sampling location shall be in the eye region. Alternate and/or additional sample probe locations may be used and will depend upon the mask system being tested. Sampling is accomplished with short length of tubing that connects the sample probe(s) in the mask to the aerosol detector unit. The method in which the sampling probe(s) is used shall not interfere with respirator performance and shall minimize sampling biases. When sampling in the eye cavity, the optimum position of the sampling probe is approximately 1/4 inch from the skin halfway between the eyes. When sampling in the oral/nasal cavity, the optimum sampling probe position is approximately 1/4 inch from the skin at the point of quadrilateral symmetry of the mouth and nose. The exact position(s) of the sample probe(s) will depend upon the design of the mask being evaluated.

4.8 Fit factor data calculations shall be performed in accordance to Appendix B.

5.0 Use of Non-standard Fit Test Systems:

5.1 When a system is used other than the standard fit testing system, a valid correlation to the standard must be determined.

5.2 Services selecting non-standard instrumentation and/or non-standard challenge atmosphere (aerosol or vapors) shall be responsible for developing and validating the correlation methodology used. When appropriate, conversion factors shall be determined to convert non-standard test data into values that would be observed using the standard fit test system. Appendix C provides an example of the correlation methodology used to compare fit factor results obtained from a non-standard aerosol system (e.g. a salt fog system) to the standard corn oil fit test system.

6.0 Reporting of the Results:

6.1 Results of all fit factor testing will be reported in terms of values that would be observed under the standard reference test conditions (Section 4.0). As a minimum, fit factor testing reports shall include the following:

(1) Test conditions and procedures

(2) Sizing/Fitting/Donning techniques

(3) Description of statistical analysis

(4) Overall fit factor results for each subject along with fit factors by exercise (as defined by paragraphs 2 and 3 of Appendix B)

(5) Anthropometric data for each subject

(6) Method and conversion factors used to calculate fit factors (when using a non-standard test system)

TABLE 1

EXERCISE PROTOCOL FOR MASK LEAKAGE TESTING

1.0 Core Exercises for the Non-Aircrew:

1.1 Normal breathing.
1.2 Deep breathing.
1.3 Side to side head movement (once per second).
1.4 Up and down head movement (once per second).
1.5 Recite the rainbow passage.
1.6 Facial expressions (yawning, frowning, smiling and rotating chin).
1.7 Touch the floor and reach for ceiling.
1.8 On hands and knees look up, left and right (once per second).

2.0 Core Exercises for the Aircrew:

2.1 Normal breathing.
2.2 Deep breathing.
2.3 Walk in place with side to side head movement.
2.4 Up and down head movement (once per second).
2.5 Recite the rainbow passage.
2.6 Facial expressions (yawning, frowning, smiling and rotating chin).
2.7 Touch the floor and reach for ceiling.
2.8 On hands and knees look up, left and right (once per second).
2.9 Walk up and down stairs.
2.10 Transition from ground mode to air mode
2.11 Reaching in all direction (seated).
2.12 "Check six" (seated, looking back over each shoulder).
2.13 Perform Valsalva.

3.0 Optional exercises:

3.1 Sight rifle
3.2 Move boxes
3.3 Jog/walk in place
3.4 Climb up and down stairs
3.5 Mask tension adjustment
3.6 Drink
3.7 Perform core aircrew exercises in air and/or ground mode.

APPENDIX A

Calibration Procedures for Aerosol
Characterization Equipment

1. The calibration of aerosol measuring and sampling devices is facilitated by the use of monodispersed aerosols. When the size or concentration of the aerosol, or both, are known to a sufficiently high degree of accuracy, the aerosol can be referred to as an aerosol standard. The calibration test equipment (Fig. A-1) consists of a latex microsphere generation system, an air dilution system, sampling chamber, aerosol particle counter and aerosol particle filter. A laser particle counter can be used for characterization of the aerosol (e.g., corn oil) by correlating the laser counter's test data with that of polystyrene latex spheres (PSL) of known particle size.

NOTE: It is important that the aerosol has fully equilibrated before reaching the sampling chamber. For that reason, a mixing chamber is included where dilution air is introduced separate from the sampling chamber.

2. The measurement instruments should be calibrated to manufacturers' specifications and calibration curves updated every three-month to six-month period depending on frequency of use.

3. Aerosol Calibration Procedures:

a. The laser particle counter should be calibrated with monodispersed Polystyrene Latex (PSL) particles, of sizes as indicated below, packaged as aqueous suspensions at 25 % solids, diluted with distilled water (4 drops/125 ml).

b. The concentration of polystyrene latex in the test aerosol should be directly proportional to the concentration of the PSL spheres in the solution in the atomizer.

4. Components of Aerosol Calibration Test Apparatus

a. Latex microspheres, Duke Scientific Corporation.

		Catalog Numbers	
Mean Diam. (um)	Description	15ml	100ml
0.106	Polystyrene Latex Particles	5010A	5010B
0.198	Polystyrene Latex Particles	5020A	5020B
0.305	Polystyrene Latex Particles	5031A	5031B
0.497	Polystyrene Latex Particles	5050A	5050B
0.966	Polystyrene Latex Particles	5095A	5095B
1.050	Polystyrene Latex Particles	5100A	5100B

SCHEMATIC DIAGRAM OF CALIBRATION APPARATUS

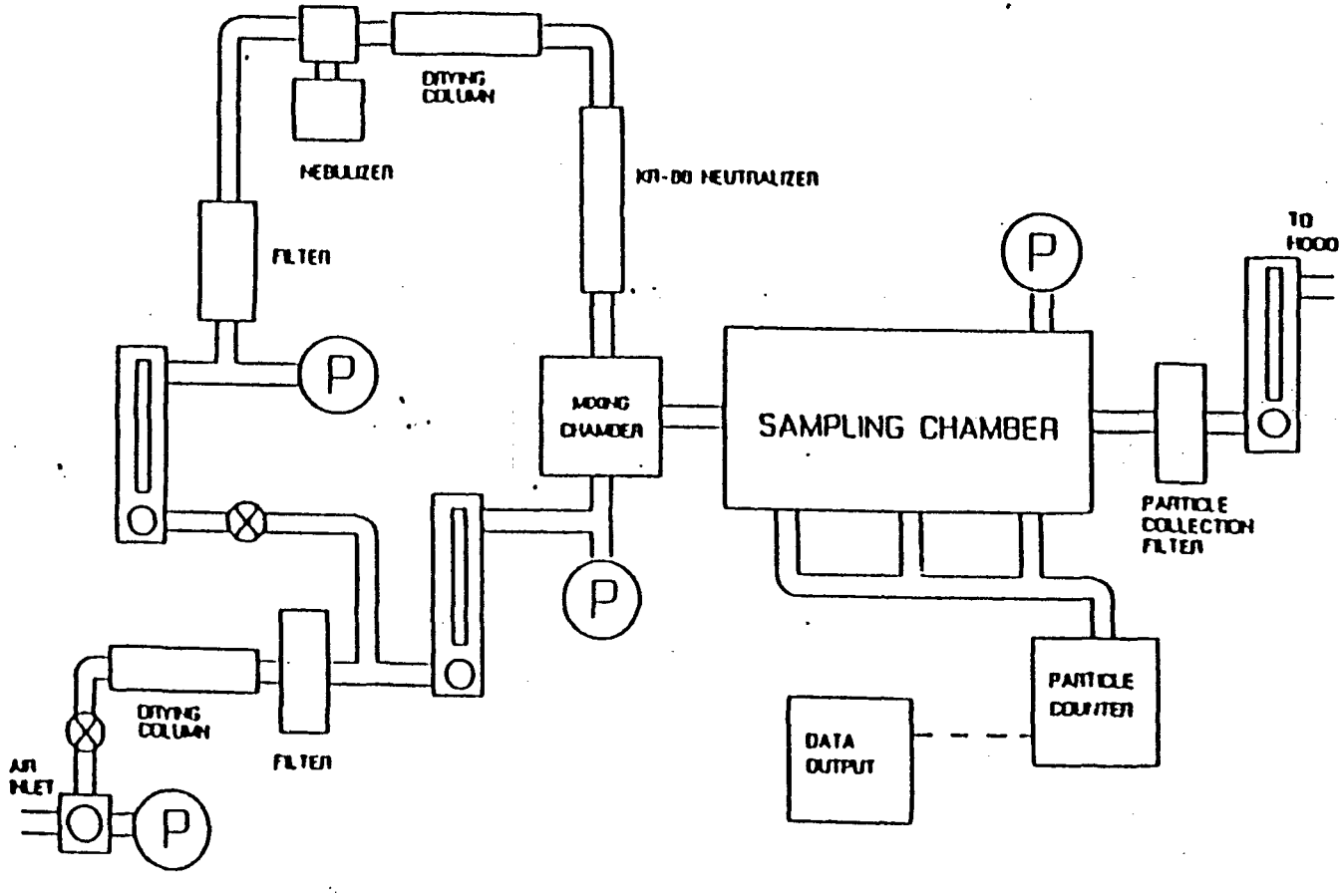


Figure A-1

b. Micro Laser Particle Counter, Model Micro LPC-HS, Measuring Systems, Inc.

c. Polystyrene Latex Filter Equipment, Nuclepore Corporation.

(1) Polycarbonate membrane 47mm.

Diam (um)	Catalog Numbers
0.2	111106
0.4	111107
1.0	111110

(2) Swinook holder 47mm.

Catalog Numbers	
1 unit	8 units
420410	420400

d. Airlife Nebulizer, American Hospital Supply, MontClair, CA.

Catalog Number
002002

APPENDIX B

Fit Factor Calculation Method

1. Fit Factor:

The protection provided by a respirator assembly against a challenge agent is expressed as the ratio of a concentration inside the respirator over a challenge concentration; this ratio is called the Penetration. The reciprocal of this ratio is called the Fit Factor. Both terms are presented by the following equations:

$$P = \frac{C_{respirator}}{C_{challenge}}$$

and

$$FF = \frac{C_{challenge}}{C_{respirator}} = \frac{1}{P}$$

where P = penetration

$C_{respirator}$ = average concentration of challenge agent inside the respirator (mg/m^3)

$C_{challenge}$ = average challenge concentration (mg/m^3)

FF = Fit Factor

2. Average Leakage Concentration per Exercise:

The results of a Fit Factor test are usually expressed by a graph showing the instantaneous ratio of the in-respirator and challenge concentrations in the form of Penetration or Fit Factor versus time. The duration of each of the exercises in this example is 60 seconds. Within one exercise, the computer collects data at the rate of two data points per second. Hence, the average penetration for one exercise can be expressed as:

$$P_{exercise} = \sum_{i=1}^{n} \frac{P_i}{n}$$

where n = the number of data points collected per one minute exercise.

and P_i = the individual measured penetration data point.

3. Overall Fit Factor:

In the same way, the overall Fit Factor, which represents the Fit Factor over the duration of the test, is expressed as:

$$\frac{1}{FF_{overall}} = \sum_{i=1}^{m} \frac{P_{exercise,\, i}}{m}$$

where m = number exercises in one complete test.

4. Data Presentation

a. The overall fit factor shall be calculated from the arithmetic mean of equally weighted exercises of aerosol penetration over the sampling period.

b. The graphical representation shall be on the log - normal scale. Data shall be transformed using log base ten prior to statistical analysis.

c. The mean, median and percent unacceptable by exercise and overall shall be reported as well as the aerosol particle size and particle numbers.

APPENDIX C

Correlation of other Fit Test Systems
to the Standard Reference System

The standardized data handling and exercise protocols are two steps needed to be able to compare fit test results from different tests in different locations. Calibration detection instrumentation to account for instrument differences is a third. Unfortunately, not all the potential differences between tests can be quantitatively accounted for because different tests will use different subject pools and fit may differ each time a person dons a mask.

Given that, a correlation method is needed to account for potential differences due to the sampling aerosol choice, the differences in aerosol generation, differences in sampling rates, both dynamics, etc.

Once a test system has been properly calibrated according to the method described in Appendix A, or in some manner appropriate to the system, a systems test using calibrated leaks is needed. In this calibrated leak device, two filters are placed in series. Also placed in line is a holder for a medical serum septum. Figure C-1 illustrates an example of a calibration apparatus.

This apparatus is placed in the test chamber and should be located as close as is practical to a typical placement for a subject's head. The sampling line is then hooked up downstream of the serum septum.

Different hypodermic needles are then used to create a series of calibrated leaks. Included are a fully closed position, where no needle pierces the septum, and a fully open, where the septum is removed.

Three different, one minute samples should be taken for each condition on three different days over a three week period. The calibrated leak device should than be sent to CRDEC where a similar test is performed with the standard reference system.

Comparing the data from the system in question and the standard reference system should provide a correlation factor. Actually, depending upon system dynamics, several correlation factors may be found, which vary depending upon the range of the leak. The number of correlation coefficients cannot be determined except on a case by case basis.

Calibrated Leak Device

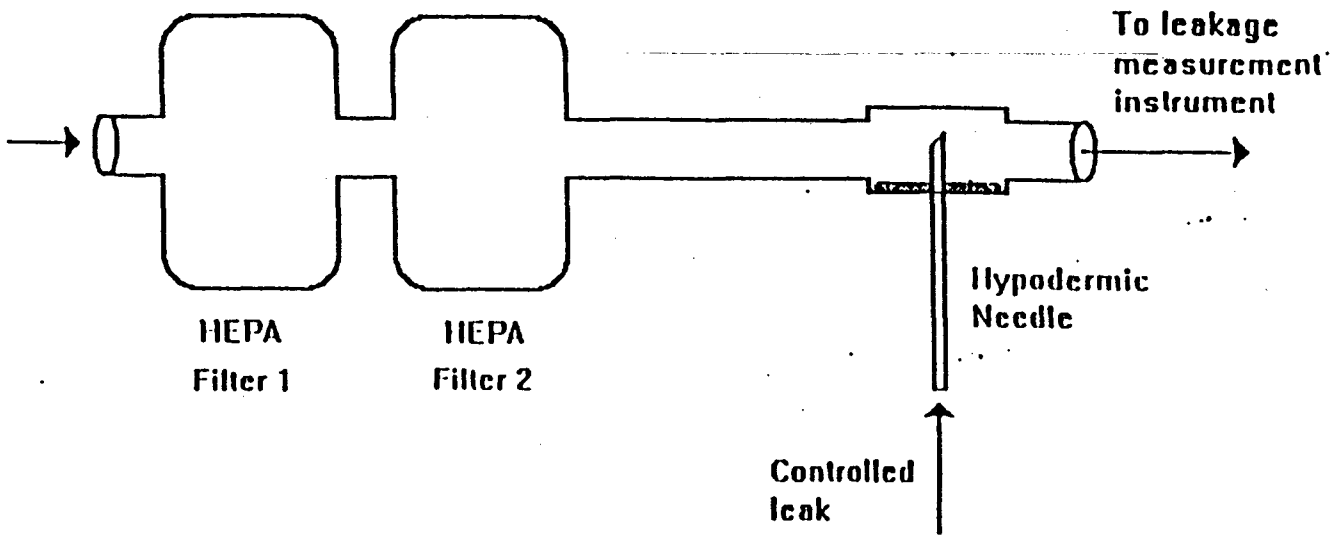


Figure C-1